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THE INTERNATIONAL NICKEL COMPANY (MOND) LIMITED

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CHANGE OF NAME

The Mond Nickel Company Limited, an affiliate of The International Nickel Company of Canada, Limited, announces that from February 28th, 1961, it will change its name to The International Nickel Company (Mond) Limited.

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Saturation Magnetostriction Constants of Nickel in the Range −196° to +365°C.

R. R. BIRSS and E. W. LEE: 'The Saturation Magnetostriction Constants of Nickel within the Temperature Range −196° to 365°C.'

Proc. Physical Soc., 1960, vol. 76, Oct. 1, pp. 502–6.

In previous determinations of magnetostriction constants, the use of the strain-gauge technique has been restricted almost exclusively to measurements at room temperature, because (1) the gauge factor is usually known only at that temperature, and (2) the problem of drift at any other temperature has always been regarded as so serious as to prevent the measurement of the small static magnetostrictive strains. The present investigators have, however, overcome these difficulties, and it is now possible, using strain gauges, to make accurate measurements of magnetostriction constants, over a wide range of temperature, in a manner which eliminates completely the uncertainties connected with the use of the demagnetized state. In this paper they report measurements on nickel carried out in this way.

The results of the investigations are summarized as follows:

'The spontaneous magnetostriction of cubic crystals can be expressed in the form

$$\lambda = C_0 + C_1(\alpha_1^2\beta_1^2 + \alpha_2^2\beta_2^2 + \alpha_3^2\beta_3^2) + C_2(\alpha_1\alpha_2\beta_1\beta_2 + \alpha_2\alpha_3\beta_2\beta_3 + \alpha_3\alpha_1\beta_3\beta_1),$$

where the α_i and β_i are, respectively, the direction cosines of the magnetization vector and the measuring direction, with respect to the crystal axes. The coefficients C_1 and C_2 have been determined for nickel within the temperature range −196°C. to the Curie point (365°C.), using calibrated strain gauges. At −196°C., $C_1 = -85{\cdot}0 \times 10^{-6}$ and $C_2 = 85{\cdot}4 \times 10^{-6}$. Both constants increase monotonically to zero at 365°C. The room-temperature (20°C.) values are $C_1 = -77{\cdot}2 \times 10^{-6}$ and $C_2 = -70{\cdot}0 \times 10^{-6}$. For a polycrystal the spontaneous magnetostriction may be expressed in the form

$$\lambda = C + \tfrac{3}{2}\lambda_s \cos^2 x,$$

where x is the angle between α and β. Measurements of λ_s have been made in the same way, and they are in good agreement with the values calculated assuming uniform stress, namely $\lambda_s = \frac{4}{15}C_1 + \frac{1}{5}C_2$.

Chemisorption of Oxygen on Nickel and Reduction of Nickel Oxide by Hydrogen

J. S. ANDERSON and D. F. KLEMPERER: 'Photoelectric Measurements on Nickel and Nickel-Oxide Films.'

Proc. Royal Soc., Series A, 1960, vol. 258, Oct. 25, pp. 350–76.

In the oxidation of metals, the reduction of oxides and many catalytic reactions, electron-transfer processes are involved in one or several stages, and it follows that changes in the work function of the surface should afford a sensitive measure of molecular polarizations, electron transfers and rearrangement processes occurring on the surface. In the investigation described, a study was made of the changes in work function accompanying the chemisorption of oxygen on evaporated nickel films, the progressive formation of an oxide film, and the subsequent reduction of nickel oxide to the metal by hydrogen. Measurements were made of changes in the spectral sensitivity of surfaces prepared under varying conditions, and in the photoelectric yield (at constant photon energy) during the admission of gas.

The results of the investigation and the conclusions drawn are summarized by the authors as follows:

'Admission of oxygen to nickel films at 20°C. resulted in several distinct effects. Lightly oxidized films (<1 monolayer equivalent total uptake) gave composite spectral sensitivity curves. By using the Fowler equation in the form of a plot of frequency against (photoelectric yield)$^{\frac{1}{2}}$, these were analyzed in terms of two work functions, which remained unaltered until the films were saturated with respect to the rapid chemisorption of oxygen. As further quantities of oxygen were absorbed, both work functions rose.

'When the films were stood *in vacuo*, the lower work function decreased, finally reaching a lower value than that measured for clean nickel; at the same time, the films recovered the capacity to adsorb oxygen. The process is regarded as identical with the known 'thermal regeneration', namely, the ability of oxidized films to take up oxygen rapidly after they have been heated *in vacuo* at 200° to 400°C. Although the lower work function fell markedly as thermal regeneration occurred, the larger work function did not fall below about 5·7 eV. It is considered that the observations point to two kinds of surface structure in the lightly oxidized films. The work function of 5·7 eV is assigned to areas thinly covered with the nickel-oxide crystal lattice, while the lower work function is assigned to areas on which the oxide, as such, does not form. It is suggested that the initial interaction of oxygen with the surface is

largely non-polar, and that nickel oxide only forms on certain areas as a result of migration, charge transfer and rearrangement. Those parts of the surface not covered with the nickel-oxide crystal lattice undergo modification, as a result of penetration of oxygen into the surface layers of the metallic lattice.

'Photoemission from nickel-oxide films (>1000Å thick) has been examined, and the interaction of hydrogen with these films was studied in detail. Changes in photoelectric yield show that there is some small degree of chemisorption at 20°C., and it is postulated that this represents formation of H_2^+ which either penetrates the nickel-oxide lattice or occupies vacant cation sites in or near the surface. At higher temperatures the surface potential becomes increasingly negative as dissociative chemisorption takes place extensively by the mechanism already recognized. With the desorption of water and the continuation of reaction, nuclei of nickel form. The findings are in agreement with, but amplify, the accepted generalized model for oxidation and reduction process.'

Electrochemical Behaviour of the Nickel-Oxide Electrode

P. L. BOURGAULT and B. E. CONWAY: 'The Electrochemical Behaviour of the Nickel-Oxide Electrode. Part II. Quasi-Equilibrium Behaviour.'

Canad. Jnl. Chemistry, 1960, vol. 38, Sept., pp. 1557–75.

In *Part I* of the paper (*ibid.*, 1959, vol. 37, p. 292), the authors examined the kinetic behaviour of the 'overcharged' nickel-oxide electrode with regard to rates of self-discharge and oxygen evolution. In the present paper, they report data on the 'quasi-equilibrium' potentials of the nickel-oxide electrode in aqueous potassium-hydroxide solutions (the behaviour of the electrodes is referred to as 'quasi-equilibrium' because the electrodes are continuously losing charge on open-circuit by the corrosion type of process previously described).

The potential of partially-charged nickel-oxide electrodes was studied (at a controlled formal state of oxidation) as a function of potassium hydroxide and water activity in aqueous alkali solutions, using a polarization decay method in which the reversible potential is approached both from the anodic and cathodic directions. Data obtained by the decay method were compared with the e.m.f. values from 'stationary' potential measurements (i.e., at very long times) and the nature of the potentials measured by these procedures was deduced. These determinations permitted evaluation of the rôle of potassium hydroxide and water in the overall potential-determining reaction. The electrode was charged to a mean state of oxidation corresponding to 50 per cent. Ni II and 50 per cent. Ni III.

The results are discussed in terms of the stoichiometry of the potential-determining reaction, and the distinction between mixed and true reversible potentials is drawn.

ELECTRODEPOSITION AND OTHER COATING METHODS

Literature Review of Plating Developments in 1960

N. HALL: 'Technical Developments of 1960.'

Metal Finishing, 1961, vol. 59, Jan., pp. 36B–36K, 93.

This survey of technical developments in plating and associated fields reported in the literature published in 1960 is based on a *bibliography* of 386 items. The information covered is reviewed, according to subject matter, in sections and sub-sections headed: cleaning; pickling; polishing (mechanical, chemical and electrolytic, barrel finishing); anodizing; treatments for deposit adhesion; metallic coatings (nickel, chromium, copper, cadmium, zinc, tin, alloys, miscellaneous metals); electroforming, metallizing, vapour coating; conversion films—protective measures; testing and control; waste treatment; miscellaneous.

Recent Developments in Nickel Plating

H. C. CASTELL: 'Nickel Plating: A Review of Recent Developments.'

Electroplating and Metal Finishing, 1961, vol. 14, Jan., pp. 6–14.

This paper, which is one of four presented at a Symposium on Nickel/Chromium Plating organized by the London Branch of the Institute of Metal Finishing in November, 1960, was abstracted, from the preprint then available, in *Nickel Bulletin*, 1961, vol. 34, No. 1, p. 8.

Notes on Improved Nickel/Chromium-Plating Processes

H. J. BACHE: 'Notes on Improved Nickel-Chromium Processes.'

Electroplating and Metal Finishing, 1960, vol. 13, Dec., pp. 451–5, 472.

In recent years, much work has been carried out with the aim of improving the corrosion-resistance of nickel/chromium deposited coatings. The results of this work, which are now coming to light, present a somewhat confusing picture. This article was written in an attempt to clarify the situation.

The author's notes cover the following systems:

(1) Bright nickel+HTHR* chromium (including proprietary crack-free chromium).
(2) Duplex-nickel systems.
(3) Duplex chromium.
(4) Sandwich coatings (Ni/Cr/Ni/Cr or Cu/Cr/Ni/Cr).

The information presented was derived from accelerated-corrosion and static and mobile outdoor-corrosion tests carried out by Electro-Chemical Engineering Company, Ltd., and the Udylite Research Corporation of Detroit.

* High-temperature, high-ratio.

The conclusions drawn from the evaluation of the four systems are summarized as follows:

'1. At the present state of development, the system which, without question, shows the best corrosion-resistance is the sandwich process employing nickel (or copper)/chromium/bright-nickel/chromium. This is true, irrespective of whether components so treated have been subjected to accelerated-corrosion or atmospheric-exposure tests.

'2. Dual-nickel deposits have shown marked superiority in accelerated-corrosion tests and in marine atmospheres. Improved corrosion-resistance has also been obtained on mobile test sites, especially where much salt is used on the streets in the winter time, as in Detroit. Although the superiority of dual nickel, as compared with bright nickel, has not been so much in evidence when studying the results from roof-exposure tests, the present trend in the United States is definitely in favour of the increasing use of dual nickel.

'3. Judgment of dual chromium must be deferred for the time being.

'4. Finally, if technical and economic objections can be overcome, the motor industry may, in the not too distant future, consider the combination of nickel (or copper)/chromium/dual-nickel/chromium as the most satisfactory answer to the corrosion-resistance problem.'

Atmospheric-Corrosion Tests on Nickel/Chromium-Plated Zinc-base Die Castings and Steel

D. M. BIGGE: 'Decorative Plated Coatings of Improved Durability.'

Plating, 1960, vol. 47, Nov., pp. 1263–8.

Since previous test programmes had indicated the improvement in corrosion-resistance achievable by increasing the thickness of the nickel constituent of nickel/chromium electrodeposited coatings, this factor, and the corrosion-resistance of semi-bright-nickel + bright-nickel composite coatings, formed the main subjects of investigation in the atmospheric tests now reported.

Zinc die-cast test panels were plated with 0·3 mil of copper + either 0·5 or 0·9 mil of nickel + 0·01 mil of chromium. The nickel layer consisted either of bright nickel *per se* or a combination of semi-bright nickel + bright nickel. The steel panels were plated with either 1·0 or 1·5 mil of nickel + 0·01 mil of chromium. The nickel constituent of the coatings was deposited by virtually every commercially used plating process: sixteen nickel-plating processes were used in the plating of the zinc-base die-cast test panels, and twenty-eight in the plating of the steel panels. Duplicate sets of steel panels plated with each process were provided for testing, one set being exposed in a bent, the other in an unbent, condition: each set comprised five duplicate test panels. Four test panels plated by each process studied were exposed at each of the following test sites: Miami, Florida; Detroit, Michigan; Pittsburgh, Pennsylvania. The fifth panel of each lot was evaluated by the 'Corrodkote' test, as a means of correlating the results of accelerated tests with those of outdoor performances (*see*, in this connexion, a paper by the same author referred to in *Nickel Bulletin*, 1960, vol. 33, No. 4, p. 73). In discussing the results of these tests, the author refers also to (1) data derived from plated parts exposed on cars in service in the Detroit area, and (2) data derived from plated steel panels which were exposed for 18 months at Kure Beach to determine whether the durability of duplex-nickel coatings would be improved by increasing the thickness of the bright nickel constituent, and whether the performance of a 2-mil coating of bright nickel would exceed or equal that of a 1·2-mil semi-bright-nickel + bright-nickel coating.

The results of the atmospheric-exposure tests at Miami, Detroit and Pittsburgh are deemed to warrant two conclusions:

(1) In the plating of zinc-base die castings the use of a buffed-Watts-nickel or a semi-bright-nickel + bright-nickel coating gives a performance decidedly superior to that associated with the use of bright nickel.

(2) Both on bent and unbent steel panels, the performance of a semi-bright-nickel + bright-nickel composite is superior to that of bright nickel.

The atmospheric tests on nickel/chromium-plated steel panels at Kure Beach demonstrated that the durability of substantially thicker single coatings of semi-bright or bright nickel is not as satisfactory as that associated with semi-bright-nickel + bright-nickel composite coatings.

Atmospheric Corrosion-Resistance of Nickel/Chromium-Plated Aluminium Sheet

R. C. SPOONER and D. P. SERAPHIM: 'Nickel-Chromium-Plated Aluminium Sheet.'

Metal Finishing, 1960, vol. 58, Dec., pp. 40–4, 47; 1961, vol. 59, Jan. pp. 37–41.

A major problem in the plating of aluminium and its alloys has been the elimination of the surface oxide film so that direct bonding is secured between the substrate and the initial metal layer. Various methods have been developed to solve this problem, the three major pre-plating techniques being the zincate treatment (in which a thin displacement zinc coating is formed by immersing the aluminium in an alkaline sodium-zincate solution), the Vogt process (which employs unusual cleaning methods, followed by flash plating of zinc and brass deposits), and anodizing treatment in phosphoric or oxalic acid. The investigation described by the authors was undertaken in an attempt to develop a means of depositing an adherent, corrosion-resistant copper/nickel/chromium coating which would render aluminium competitive with other plated metals in such fields as the automotive and the hardware.

The relative efficacy of the three pre-plating procedures was studied in tests in which panels of 3S

aluminium alloy were, after pre-treatment, plated with a copper/nickel/chromium coating and then exposed in semi-rural and severe industrial atmospheres for up to two years. The panels pre-treated by phosphoric-acid anodizing or by the zincate process were plated with nickel to thicknesses of 0·5, 1·0 or 1·5 mil; the nickel coating on those pre-plated by the Vogt process was 1 mil thick. Full details are given of plating procedures, test conditions and the results obtained.

The performance of panels treated by phosphoric-acid anodizing was good, particularly in relation to freedom from blistering or flaking. During industrial exposure the panels processed by the zincate and Vogt techniques failed, due to severe blistering, within a year. The weathering resistance of all the panels tested increased with increase in nickel thickness, and it is concluded that panels intended for applications involving severe industrial exposure required a nickel coating at least 1·5 mil thick. Use of recently improved nickel/chromium plating techniques should, it is considered, greatly increase corrosion-resistance.

Stress in Electrodeposited Metals

I. L. NEWELL: 'Stress in Electrodeposited Metals.'
Metal Finishing, 1960, vol. 58, Oct., pp. 56–61.

Residual stress produced in electrodeposited metals during plating is discussed by the author in sections concerned with: measurement of residual stress; influence of stress on the properties of the deposits; theories of stress formation in electrodeposits; stress in electrodeposited copper; stress in electrodeposited zinc, lead and cadmium; stress in electrodeposited chromium; and stress in electrodeposited nickel.

Influence of Surface Preparation on the Tensile Strength, Hardness and Adhesion of Electrodeposited Nickel

P. A. BROOK: 'The Effect of Surface Preparation on the Tensile Strength, Hardness and Adhesion of Electrodeposited Nickel.'
Plating, 1960, vol. 47, Nov., pp. 1269–73.

The literature relating the properties of electrodeposits to the variables of the plating process is extensive, but comparatively little information is available on the influence of the cathode surface on the mechanical and physical properties of the electrodeposit. In the present paper the author reports the results of an investigation in which the tensile strength, hardness and adhesion of nickel, electrodeposited from a Watts solution under carefully controlled conditions, was determined as a function of the surface preparation to which the copper substrate was subjected.

Tensile tests were carried out on unstripped samples as they came from the plating bath, using a method based on the Williams-Hammond modification of the Ollard test (*Trans. Inst. Metal Finishing*, 1954, vol. 31, p. 124). Full details are given of the surface preparations used.

Statistical analysis of the results obtained revealed that tensile strength and hardness were both independent of the surface preparations employed. The ratio of hardness to tensile strength established by the author agrees with previously reported values. Adhesion of the nickel deposits was found to be markedly influenced by the surface preparation: in particular, it was found that mechanically scoured surfaces were associated with minimum adhesion, and electropolished surfaces with some of the highest values obtained.

Determination of the Thickness of Electrodeposits by the Electrolytic-Stripping Method

P. B. MATHUR: 'A Precision Instrument for Testing the Thickness of Electroplates by Electrolytic Stripping Method.'
Plating, 1960, vol. 47, Nov., pp. 1274–6.

In the determination of the thickness of electrodeposits by the anodic-stripping method, a small predetermined area of the plated component is electrolytically de-plated at constant current density, the end point of stripping being indicated by a sudden change in the voltage reading of a voltmeter connected in parallel with the cell. In this paper, details are given of a simple instrument which permits precise determination of the thickness of various metal coatings by this method.

The instrument incorporates a current divider for the precise adjustment of the current, a potential divider for controlling the sensitivity of the voltmeter or potential recorder, and a voltage-balancing arrangement for balancing the initial voltage across the stripping cell. The end-point indication is made by a sensitive voltmeter or a potential recorder.

The results of experiments to establish the stripping solutions for use with various deposit/basis-metal combinations will, it is stated, be published in due course.

Reactions between Nickel Electrolytes and Plating Anodes

O. STÖRING: 'Reactions between Nickel Electrolyte and Nickel Anode: Practical Review.'
Galvanotechnik, 1959, vol. 50, July 15, pp. 348–61.

Although the relationships between the cathode and electrolyte in nickel plating have been the subjects of much attention, relatively little information has been published on the factors influencing the reactions between anode and electrolyte. The present review was written with the aim of throwing light on the practical significance of these factors in the operation of bright-nickel-plating solutions.

The paper is in three main sections. In the first, which is concerned with the nickel electrolyte, the author draws attention to: the salient characteristics of nickel-sulphate and nickel-chloride solutions; the influence of the hydrogen-ion concentration,

the anodic current density, the solution temperature and chloride ions; the advantages of simultaneous circulation and filtration of the electrolyte; and the rôle of brightening and wetting agents.

The second section is devoted to discussion of commercial nickel anodes, and covers the need for maintaining good contact between current and anode, the requirements of German, British and American standards, and the characteristic features of the electrolytic anode, the rolled anode, the depolarized anode, and the carbon-containing anode.

The short final section is concerned with the relationship between anode losses and anodic current density.

Experience with Bright-Nickel-Plating Solutions

G. BUSS: Experience with Some Bright-Nickel-Plating Solutions.'

Electroplating and Metal Finishing, 1961, vol. 14, Jan, pp. 15–17.

It is known that the properties of deposits from bright-nickel-plating solutions containing organic brighteners deteriorate, due to decomposition of the addition agents, as the solution ages. Investigations by J. EDWARDS have shown that both Canning 'Super-Gleamax' and 'Efco-Udylite No. 31' solutions gave good deposits up to a total loading of 270 ampere-hours/L., after which the tensile stress rose steeply and ductility decreased. Edwards' recommendation to filter continuously through active carbon is deemed by the present author to be normally impracticable, due to the adsorption of most brighteners and wetting agents, while periodic regeneration of the whole bath at frequent intervals takes up much time, is expensive and usually requires a storage tank. Since this work was carried out, bright-nickel-plating solutions have been developed which can be filtered continuously through activated carbon. In Germany, the author's company (Daimler-Benz A.G.) installed 3,670 gals. of such a solution in July 1958, and converted another 7,340 gals. in November of the same year.

The present paper comprises an account of the Company's experience in the use of this solution and that of the two previously employed. Operating data found to be optimum are presented and discussed, and the paper includes notes on chemical and brightener additions.

Barrel-Plating Procedures and Solutions

F. J. LA MANNA: 'Barrel Plating.'

Metal Finishing, 1960, vol. 58, Sept., pp. 52–5; Oct., pp. 66–70.

The review is in two main sections. In the first, which is concerned with barrel-plating apparatus and procedures, the author, after discussing the types of plating barrels in current use, considers the advantages and disadvantages of the process. He then discusses the factors which are essential to an understanding of the plating process and to the achievement of optimum results, and, in this connexion, considers the determination of barrel efficiencies and work loads, current requirements, the distribution of components in the barrel, parts not suitable for barrel plating, and pre-plating operations. Attention is drawn to a graph correlating load size with the time required to obtain a desired thickness of nickel or zinc, and the first section concludes with notes on such practical points as cleaning and acid dipping, the plating of parts which nest or float, drying, purification of plating solutions, the effects of overloading and underloading, and the use of appropriate current densities.

In the second section the author gives details of typical barrel-plating solutions which are stated to be adaptable to the requirements of a specific application. Deposition of the following metals and alloys is covered: brass, bronze, cadmium, chromium, copper, gold, iron, lead, nickel, rhodium, silver, tin, zinc.

Direct Nickel Plating of Hardenable Stainless Steel

B. E. SCOTT: 'Direct Nickel Plating of Hardenable Stainless Steel.'

Metal Finishing, 1960, vol. 58, Nov., pp. 48–52.

The work reported was initiated in an attempt to develop a coating which would prevent the corrosion to which compressor rotor blades fabricated from Type 410 chromium stainless steel were found to be subject during service in a jet aircraft engine. Exploratory tests showed that electrodeposited nickel coatings satisfied the requirement of abrasion-resistance, and that the smooth bright deposits obtainable would not detract from the airflow characteristics of the blade. Use of an initial Wood's nickel strike as an undercoating for a standard nickel coating adversely affected the fatigue strength of the steel, and, since the data available indicated that no significant loss in fatigue strength would result from use of nickel coatings deposited from a sulphamate solution (i.e., deposits with compressive stress), an attempt was made to deposit this type of nickel without an undercoating. The development of a suitable plating procedure, and the tests carried out to assess the efficacy of the nickel deposits as protective coatings, form the subjects of the present article.

Steps are being taken to obtain patent rights over the plating procedure finally evolved, details of which are reproduced below:

(1) Degrease to remove oil.
(2) Apply stop-off to unplated areas.
(3) Vapour blast, if desired.
(4) Assemble on rack.
(5) Anodic alkaline clean: 1-2 minutes at 6 volts.
(6) Hot and cold water rinse.
(7) Immerse in C.P. hydrochloric acid, concentrated, at room temperature for 2 minutes, or in 50 per cent. C.P. hydrochloric acid at 120°–130°F. (50°–55°C.) for 2 minutes.
(8) Cold-water rinse, 30 seconds, maximum.

(9) Immerse in nickel-sulphamate activator (pH reduced to 1 with sulphamic acid) for 2 minutes at room temperature.

(10) Without rinsing, and within 20 seconds, transfer to the sulphamate nickel-plating bath. Make current contact prior to entering the batch. Strike at a minimum current density of 80 amp./sq. ft. (8·64 amp./dm.^{2}) for 1 minute or until the item is completely covered with nickel.

(11) Plate at 20 amp./sq. ft. (2·16 amp./dm.^{2}) for the time necessary to produce the deposit thickness required.

(12) Hot- and cold-water rinse.

(13) Dry.

(14) Heat-treat ½ hour at 375°F. (190°C.).

Tests on plated specimens revealed the nickel coating to have no significant effect on the fatigue strength of the basis metal, and no embrittlement occurred as a result of the plating cycle. Further tests, under conditions simulating those encountered during engine operation, confirmed that the fatigue life of the compressor blades was unaffected by nickel plating, while the results of salt-spray corrosion tests provided evidence of the adequate protection against corrosion conferred by the nickel deposit.

Electrodeposition of Nickel-Cobalt Alloys

A. J. STEIGER: 'Electrodeposition of Nickel-Cobalt Alloys: Russian Research and Development.'

Metal Finishing, 1960, vol. 58, Dec., pp. 53–55.

This article is based on a report, in the Russian journal *Vestnik Maschinostroenie*, of experiments in which nickel-cobalt coatings, of constant composition and 3–4 mm. thick, were deposited using separate nickel and cobalt anodes. The hardness of the coatings increased with increase in cobalt, attaining a maximum at a content of 40 per cent., thereafter remaining constant. Microstructurally the deposits were characterized by the presence of dendrites and wide and narrow bands parallel to the deposition surface.

The investigation described, undertaken to develop a plating process suitable for use in the manufacture of moulds employed in forming and casting plastics, involved study of (1) the dependence between the relative concentrations of nickel and cobalt salts, and (2) the influence of current density, pH and agitation on the composition of the deposits obtained.

Deposition of Nickel-Zinc Alloys from Pyrophosphate Solutions

T. L. R. CHAR and S. K. PANIKKAR: 'Electrodeposition of Nickel-Zinc Alloys from the Pyrophosphate Bath.'

Electroplating and Metal Finishing, 1960, vol. 13, Nov., pp. 405–12.

Previous experiments having shown the pyrophosphate solution to be suitable for electrodeposition of nickel and zinc (*see*, with respect to nickel, abstract in *Nickel Bulletin*, 1959, vol. 32, No. 8, p. 251), the investigation now reported was conducted in an attempt to codeposit the two metals from this type of solution.

Exploratory experiments demonstrated that deposition of nickel-zinc coatings was feasible, and, subsequently, deposition was carried out under conditions varying with respect to electrolyte concentration, addition agents, pH, temperature and agitation. The data derived from a detailed study of the influence of these variables on the composition and structure of the deposits, the cathode efficiency and the cathode potential are presented by the authors.

Optimum conditions for deposition of satisfactory alloy coatings (ranging in nickel content from 21 to 84 per cent.) were found to be:

Solution Composition	g./L.
nickel	17·6
zinc	19·6
pyrophosphate	260·6
pH 9	
temperature .. 60°C.	
cathode current density 0·25–15 amp./dm.^{2}	
cathode efficiency 9–49 per cent.	

Use was made of nickel and zinc anodes.

Electrodeposition of Iron-Chromium-Nickel Alloys: Influence of Brightening Agents

W. MACHU and M. F. M. EL-GHANDOUR: 'Influence of Brightening Agents on the Electrodeposition of Iron-Chromium-Nickel Alloys.'

Werkstoffe u. Korrosion, 1960, vol. 11, Oct., pp. 628–31.

In previous studies the authors had investigated the feasibility of depositing iron-chromium-nickel alloys approximating to the composition of an 18–8 steel, and had established optimum plating conditions for the solution finally selected as most promising: *see* papers abstracted in *Nickel Bulletin* 1960, vol. 33, No. 10, pp. 239–240. Since the brightness of the coatings deposited under these conditions was unsatisfactory, the experiments now reported were undertaken to determine the effects of adding various organic and inorganic brightening agents to the solution.

The data recorded show that, in most cases, the brightening agents had little or no beneficial influence on the brightness of the alloy deposit, a result which the authors attribute to the presence of a chromium-hydroxide film on the cathode surface which interferes with the formation of the necessary adsorption film by the brightening agent (*see* papers previously referred to).

The brightening agents lowered the current efficiency, and, in this respect, their effect was similar to that of inhibitors.

NON-FERROUS ALLOYS

Thermodynamics of the Chromium-Nickel System

O. KUBASCHEWSKI, W. A. DENCH and G. HEYMER: 'The Thermodynamics of the Chromium-Nickel System.' *Zeitsch. f. Electrochemie*, 1960, vol. 64, Sept., pp. 801–5.

Employing an improved technique of vapour-pressure measurement (combining the Knudsen effusion method with the use of radioactive tracers), the authors studied the activity of chromium in chromium-nickel alloys at 1400°–1600°K. With the aid of a high-temperature calorimeter, the heats of formation of the solid solutions in nickel in the range 1220°–1310°K. were also established.

The thermodynamic data obtained are in approximate agreement with the results of previous investigations. The available data are critically evaluated, particularly in relation to the light they throw on the phase boundaries of the system, and the possibility of the existence of a high-temperature phase is not excluded.

Low-Temperature Properties of Nickel-containing Alloys

See abstract on p. 47.

Use of 'K Monel' for the Arresting Hooks of Carrier-based Aircraft

See abstract on p. 51.

NICKEL-IRON ALLOYS

Thermal and Magnetic Analysis of an Iron-Nickel Alloy by an Electron-Beam Technique

S. YAMAGUCHI: 'Thermal and Magnetic Analysis of an Fe-Ni Alloy by an Electron-Beam Technique.' *Jnl. Iron and Steel Inst.*, 1960, vol. 196, Dec., p. 462.

In the present study, carried out on 'Invar' powder (35 per cent. nickel), an electron beam of a certain wavelength was employed to heat a test piece for diffraction analysis of its crystal structure and for magnetic analysis using the Lorentz effect.

The particles in the specimen (grain-size about 1000Å) were held to the sharp edge of a razor blade acting as permanent magnet (remanence about 10,000 G), and so were kept in the saturation induction (15,000 G). An electron beam (0·1 mm. cross-section, 0·05 mA current, 0·0299Å wavelength), grazing these magnetized particles, produced their diffraction pattern. (In this case, not only should the path of the electrons become deflected by the magnetic field of the specimen, but the temperature of the specimen should be raised through bombardment by the fast electrons.)

The process of double exposure carried out to investigate the relationship between the temperature and magnetic induction of the specimen is described.

Nickel-Iron-Manganese Glass-to-Metal-Sealing Alloy for Microwave Tubes

W. DÜSING: 'A New Chromium-free Plateable Fe-Ni Alloy for Sealing-in to Lead Glass.' *Glastechnische Berichte*, 1960, vol. 33, No. 7, pp. 257–61.

The investigation described was undertaken to develop a sealing alloy which would be suitable for use in the construction of housings for microwave tubes operating at high frequencies, and which would (1) match the expansion coefficient of the lead glass selected for use in the tube, and (2) be readily plateable.

Exploratory tests had indicated that the most promising material for further study was a 54–46 nickel-iron alloy, which, though easily plated, exhibited a coefficient of expansion only just adequate to render it suitable for use with lead glass under limited service conditions. In subsequent studies, attempts were made to determine the feasibility of improving the match between the glass and the alloy by appropriate additions of copper or manganese. These tests culminated in the development of an alloy which, containing nickel 48, iron 47, manganese 5, per cent., satisfied all requirements. The alloy is readily electroplated with an adherent noble-metal coating, can be fabricated as easily as the original iron-nickel alloy, and provides a satisfactory glass-to-metal seal. Tubes made with the alloy by normal manufacturing methods were still gas-tight after life tests of up to 1000 hours and after five months' storage.

CAST IRON

Production, Properties and Applications of Cast-Iron Bar

J. CUMBERLAND: 'Production and Properties of Cast-Iron Bar.' *Foundry Trade Jnl.*, 1960, vol. 109, Oct. 27, pp. 523–33.

Cast-iron bar in stock sizes has been available for many years, and in the engineering industry has, to a great extent, supplanted the use of individual sand-castings for the production of small essentially-cylindrical components. The demand for cast-iron bar to be machined into a wide range of engineering components has induced the foundry industry to standardize quality, and to rationalize production on as repetitive and economic a basis as possible. In the introduction of the present paper, the author briefly alludes to the production of bar in static

graphite dies, and goes on to comment on the continuous-casting process and the vertical-casting and horizontal-casting machines used. The use and advantages of machines of the latter type, which permit bar to be die-cast on the horizontal plane at ground level, form the main subjects of the paper.

The horizontal continuous-casting machine employed in the production of bar at Sheepbridge Alloy Castings, Ltd., is described, operational procedures are outlined, and the diameter-sizes obtainable by the process are discussed. Two grades of iron are regularly produced by both the static-die-casting and continuous-casting techniques. By far the greatest quantity of bar is cast in an unalloyed medium-phosphorus grey iron intermediate in strength between grades 12 and 14 of *B.S.* 1452. Smaller quantities of a nickel-chromium alloy iron are, however, produced for customers who require material of higher quality. The alloyed iron, which conforms to *B.S.* 1452, grade 17, is harder and stronger than the unalloyed type, and is responsive to quenching and tempering treatments which still further enhance strength and wear-resistance. (This iron is suitable for use in such components as gears, cams or rollers which are subjected to severe abrasion or indentation forces in service.) In the concluding section of the article the author presents data typifying the mechanical properties of the two grades, discusses structural characteristics, cost aspects and the size in which bar in both grades is available, and refers to some of the applications found (in particular, the use of the alloy grade for moulds employed in the production of glass bottles).

Impact-Fatigue Life of 'Ni-Hard' Grinding Balls: Influence of Heat-Treatment

R. H. T. DIXON: 'Some Effects of Heat-Treatment upon the Impact-Fatigue Life of 'Ni-Hard' Grinding Balls.'

Jnl. Iron and Steel Inst., 1961, vol. 197, Jan., pp. 40–48.

The nickel-chromium white cast iron 'Ni-Hard', combining good foundry properties with exceptional hardness and wear-resistance and moderate toughness, has established itself in industry as an abrasion-resistant material. 'Ni-Hard' is usually employed under conditions of dry and wet abrasion, and, although many such applications involve a considerable amount of repeated impact (e.g., ball- and rod-mill liners), the service stresses are generally of a low order, and it has been found that the iron has ample toughness to withstand them. Under very heavy repeated impact, however, such as is encountered by balls in a large-diameter (10–12 ft.) ball mill, breakage may occasionally occur, and the need therefore arose to increase the toughness of the iron without seriously impairing its excellent abrasion characteristics.

In the as-cast condition, 'Ni-Hard' exhibits a structure consisting of primary dendrites of austenite, which have subsequently been partly transformed to martensite on cooling, in a matrix of eutectic carbide. In the research programme described, experiments were carried out to establish a heat-treatment which would have the effect of toughening and stabilizing the austenite/martensite support phase, and hence improve the impact-resistance of the grinding balls.

Balls of the following composition were subjected to various single- and double-stage heat-treatments and then repeatedly dropped, in a ball-testing apparatus, from a height of 21 ft. (6·3 m.) onto an inclined anvil until fracture occurred: carbon 3·39, silicon 0·63, manganese 0·6, sulphur 0·089, phosphorus 0·052, nickel 3·51, chromium 1·4, molybdenum 0·01, copper approx. 0·02, per cent. The fractured balls were sectioned for micro-examination and hardness determination. Full details are given of the test apparatus and procedure employed and of the results obtained. These results are deemed to warrant the following conclusions:

'1. The impact-fatigue strength of 'Ni-Hard' is improved by the reduction of the austenite content of the as-cast material, provided that the final structure is free of pearlite: the strength of a structure free of austenite and pearlite is improved by a light tempering treatment, and the higher the proportion of tempered martensite, as distinct from bainite, the greater is the strength of the iron.

'2. Heat-treatment at 275°C. for at least 4 hours, followed by air cooling, considerably improved the life-to-fracture of a grinding ball, without lowering the hardness from its initial value of about 700 DPN.

'3. Duplex heat-treatments of three types were found to be effective in increasing life-to-fracture:

(i) sub-zero treatment, at −78°C. or below, for 4 hours, followed by tempering at 257°C. for 4 hours and air-cooling;

(ii) 'intermediate-zone conditioning' at 450°C. for 4 hours, followed by tempering at 275°C. for 4 hours and air-cooling;

(iii) 'super-critical conditioning' at 750°C. for 4 hours, followed by tempering at 275°C. for 4 hours and air-cooling.

'Treatments (i) and (iii) both resulted in an increase in hardness of about 80 points DPN: treatment (ii) produced a drop in hardness of about 30 DPN. Optimum life-to-fracture was obtained from treatment (ii).

'4. Inclusions, flake graphite, porosity, pinholes, and deep surface oxidation all have an adverse effect on life-to-fracture.

'5. Where conditions of occasional heavy single-blow impact are encountered, coupled with repeated light impact, a single heat-treatment at 275°C. should be used, since this gives the best combination of toughness under both conditions.'

To relate impact-fatigue life as measured on the drop-testing apparatus to service performance under commercial conditions, field tests were carried out, with 200 double-heat-treated 2¼-in. (5·6-cm.) diameter sand-cast 'Ni-Hard' balls, in the second compartment of a ball mill grinding dry nickel-oxide sinter. No fracture occurred in any of the

balls, and the wear factor of 'Ni-Hard' compared with forged medium-carbon-steel balls was found to be 15 to 1. The results of the field tests have been reported by the present author in *Engineering*, 1960, vol. 190, Nov. 4, pp. 598-9: see abstract and table in *Nickel Bulletin*, 1960, vol. 33, No. 12, pp. 307-8.

Study of the Heat-Affected Zone of Welded S.G. Iron

E. F. NIPPES, W. F. SAVAGE and W. A. OWCZARSKI: 'The Heat-Affected Zone of Arc-Welded Ductile Iron.'

Welding Jnl., 1960, vol. 39, Nov., pp. 465s-72s.

The thermal cycles to which spheroidal-graphite iron is subjected during arc welding may, due to the presence of the free graphite, which tends to dissolve at elevated temperatures into the austenitized matrix, seriously impair the properties of the heated-affected zone. If cooling rates are sufficiently rapid, the high-carbon-containing constituents so formed may appear as brittle martensite. Some of the dissolved carbon may also reprecipitate as secondary graphite on the existing spheroids during cooling, but some may precipitate as massive carbides, which can have a marked embrittling effect. The aim of the research now reported was to obtain data on the effects of the thermal cycles involved in welding.

A spheroidal-graphite iron of the following composition, with an almost completely ferritic matrix (95 per cent. ferrite, 5 per cent. pearlite), was selected for study: carbon 3·05, manganese 0·26, silicon 2·6, phosphorus 0·021, sulphur 0·011, nickel 2·1, magnesium 0·072, per cent. The programme was concerned, in particular, with the influence, on the microstructure and hardness of the heat-affected zones, of the maximum temperature and the cooling rate employed in the various thermal cycles to which the iron was subjected.

Weld thermal cycles were simulated using apparatus developed at the Rensselaer Polytechnic Institute. To determine the effects of pre-heat, the thermal cycles were initiated at temperatures of 72°, 210°, 400°, 600° and 800°F. (22°, 100°, 205°, 315° and 425°C.). Specimens were cycled to maximum temperatures of 1200°, 1400°, 1550°, 1800°, 2000°, 2100° and 2200°F. (650°, 760°, 845°, 980°, 1095°, 1150° and 1205°C.), and then subjected to hardness tests and microstructural examination.

Definite microstructural changes were first observed when the peak temperature of the weld thermal cycle exceeded 1550°F. (845°C.). The use of a pre-heat temperature of 800°F. (425°C.), the maximum employed, prevented the formation of massive carbides and martensite in regions which reached peak temperatures up to 2000°F. (1095°C.). At higher peak temperatures, carbides, predominantly intergranular, persisted in the microstructure even after pre-heat at 800°F. (425°C.), and large areas of eutectic structure, which formed upon solidification of a liquid phase, were present in specimens exposed to a thermal cycle involving a peak temperature of 2100°F. (1150°C.). At pre-heat temperatures of 400°F. (205°C.) and above, secondary spheroids of graphite were found to form in areas where the liquid phase had appeared.

The average hardness increased from the region of Rockwell A47 (V.P.N. 140) for the as-received material, to Rockwell A50 (V.P.N. 153) in specimens subjected to a thermal cycle with a peak temperature of 1550°F. (845°C.), and to Rockwell A78 (V.P.N. 580) in specimens exposed to a peak temperature of 2200°F. (1205°C.). Slower cooling rates, which favoured austenite-to-pearlite transformation and reprecipitation of graphitic carbon onto spheroids gave rise to microstructures with lower hardnesses for each peak temperature studied.

CONSTRUCTIONAL STEELS

Influence of Melting Method on the Properties of '300M' Steel

J. C. CHANG, F. J. HERR and J. W. SWEET: 'Modified 4340 Heat-Treated to 270,000 to 300,000 Ultimate.'

Metal Progress, 1960, vol. 78, Nov., pp. 104-10.

About seven years ago, The International Nickel Company, Inc., gave details of the properties of '300M' steel, a modification of the A.I.S.I. 4340 grade (nominal composition: carbon 0·4, manganese 0·75, silicon 1·5, nickel 2, chromium 1, molybdenum 0·4, per cent.). Basic electric heats of this steel were studied by the Aero-Space Division of Boeing Airplane Company during 1958, and the steel was, as a result, deemed an excellent material for parts requiring tensile strengths in the range 270,000-300,000 p.s.i. (120·5-134 t.s.i.: 190-211 kg./mm.^{2}). The steel was considered most suitable for use in forgings for aircraft landing gear, and even more acceptable as a material for missile motor cases and fuel tanks. Since the steel is now being made by three different processes, it was decided to evaluate the influence of the steel-making practice on the properties of forged bars. Data from the investigation are presented in this article.

Bar was obtained from heats of steel (*a*) air-melted by the basic electric process, (*b*) vacuum-induction-melted, and (*c*) consumable-electrode vacuum-melted. Specimens machined from the three groups of bar were then subjected to tests to evaluate (1) longitudinal tensile properties, (2) transverse tensile properties (using notched and unnotched specimens), (3) fatigue characteristics, and (4) susceptibility to hydrogen embrittlement after cadmium plating.

On the basis of the data presented the authors conclude that:

'Air-melted '300M' steel in bar form appears to be a good material for use after heat-treatment bringing its tensile strength into the range 270,000 to 300,000 p.s.i. It contains comparatively larger nonmetallic inclusions, which may be responsible for

the inferior ductility of tensile specimens cut transverse to the grain and for the lower endurance limit in the rotating-beam machine.

'Steel melted and cast in vacuum by either method is not as free from oxide and sulphide inclusions as one would conclude from statements made in the literature. However, it has an excellent combination of strength and ductility in the longitudinal direction and also in transverse directions in square bars when the over-all reduction from the ingot is from 3 or 4 to 1. It can be plated and baked free from damaging hydrogen. The endurance limit of short transverse bars is somewhat lower than 110,000 p.s.i. (49 t.s.i.: 77·5 kg./mm.²).

'Comparing vacuum steel (induction-melted) with metal made by the consumable-electrode method, the first is cleaner, has higher reduction-of-area in transverse direction, high elongation and impact strength, and also has much better notch-strength ratios. The latter can now be produced in larger ingots, is cheaper, and has slightly better longitudinal properties.

'The air-melted heats studied in this work were of excellent quality. Providing that optimum reduction practices are used, we believe the greatest advantage of both induction-vacuum and consumable-electrode-melted steel over air-melted is the uniformity of properties within heats and from heat to heat. The main reasons for anticipating improved uniformity in the vacuum-melted steels are (*a*) smaller inclusions, (*b*) better distribution of inclusions, and (*c*) less gas content.'

See also

Properties of '300M' Sheet

J. C. CHANG, F. J. HERR and J. W. SWEET: 'High-Strength Steel Sheet ('300M').'

Metal Progress, 1960, vol. 78, Dec., pp. 101–4.

The investigation reported, complementing that referred to in the preceding abstract, was undertaken to study the mechanical properties of sheet originating in heats of '300M' steel (*a*) melted by the basic-electric process, and (*b*) vacuum-induction-melted and -cast. (No consumable-electrode vacuum-melted sheet was available for study.)

Specimens were taken from sheet and thin plate 0·05–0·15 in. (1·25–0·375 mm.) thick. Data on the optimum heat-treatments established, and the tensile properties obtained in sheet so treated, are presented. Also reported are the results of bursting tests on small pressure tanks welded from basic-electric sheet, and tensile tests on vacuum-melted specimens at temperatures ranging from −320° to +800°F. (−195° to +425°C.).

The results of the investigation are regarded as indicative that both basic-electric and vacuum-induction-melted sheet and plate can, in the case of well-designed engineering structures, be heat-treated to a minimum ultimate strength (at 70°F.: 21°C.) of 270,000 p.s.i. (120·5 t.s.i.: 190 kg./mm.²) and a minimum yield strength of 220,000 p.s.i. (98 t.s.i.: 154·5 kg./mm.²) and still exhibit adequate ductility. The vacuum-melted sheet retained excellent strength and ductility at temperatures ranging from +400°F. to −100°F. (205° to −75°C.), but if really high strength is required at temperatures higher than 400°F., use of a higher-alloy steel is recommended. The ductility of '300M' appeared to be erratic at −320°F. (−195°C.). Although other work shows that the impact strength of the steel falls significantly at temperatures below −150°F. (−100°C.), it is stated that even at −320°F. properties are equivalent to those of the strong aluminium alloys. Strength decreases at 600°F. (315°C.) and above, but ductility is higher than at 70°F. (21°C.).

Toughness of Tempered Martensite

D. HARDWICK: 'The Toughness of Tempered Martensite.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Nov., pp. 301–8.

Toughness is of particular importance in large highly stressed forgings, and some recent failures of turbo-alternator components in the U.S.A. have concentrated the attention of metallurgists and engineers on this property. Some of the factors affecting the transition temperature of En.40B 3 per cent. chromium-molybdenum steel (a standard alternator-rotor composition) have been examined, in some detail, by CINA and JUBB (*ibid.*, 1959, vol. 193, pp. 329–49) who demonstrated the extent to which the transition temperature could be affected by prior austenite grain-size, tensile strength, the degree of temper embrittlement, and the nature of the transformation product. As part of a general programme initiated to develop improved alternator-steel compositions, the work of CINA and JUBB has now been extended to study of two further steels (En.21 3 per cent. nickel and En.25 2½ per cent. nickel-chromium-molybdenum grades), in an investigation which was partly concerned with the effect of tensile strength on the transition temperatures of tempered-martensite structures. The results obtained are recorded in the present paper.

Tensile-strength/transition-temperature relationships were determined on specimens in the tempered-martensitic condition and at a constant prior austenite grain-size. The results are rationalized in terms of the tempering characteristics of martensite.

Influence of Alloying Elements on the First-Stage of Tempering in High-Carbon Steels

H. W. KING and S. G. GLOVER: 'Influence of Alloying Elements on the First Stage of Tempering in High-Carbon Steels.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Nov., pp. 281–8.

Whilst the mechanism and kinetics of the first stage of tempering in plain-carbon steels have been the subjects of several investigations, study of the influence of the alloying elements on the tempering of martensite has been confined mainly to the later stages of the process. In the investigation described

Tensile Properties of 25% Nickel Steels
(See abstract below)

Composition and Heat-Treatment	Smooth Bar								Notched Bar			Notched to Smooth Tensile Ratio
	Yield Strength			Tensile Strength			Elongation	Reduction-in-Area	Tensile Strength*			
	p.s.i.	t.s.i.	kg./mm.²	p.s.i.	t.s.i.	kg./mm.²	%	%	p.s.i.	t.s.i.	kg./mm.²	
Composition: 24·3% Ni, 1·6% Ti.												
1500°F. (815°C.), 1 hr.†; −100°F. (−75°C.), 16 hr.; 850°F. (455°C.), 4 hr.	234,000	104·5	164·5	253,000	113	178	14	15	—	—	—	—
1500°F., 1 hr.; cold-reduced 50%; −100°F., 16 hr.; 850°F., 1 hr.	267,000	119	187·5	275,000	123	193·5	12	61	402,000	179·5	282·5	1·46
Composition: 27·6% Ni, 1·5% Ti, 0·15% Al, 0·43% Nb.												
1500°F., 1 hr.‡; 1250°F. (675°C.), 4 hr.; −100°F., 16 hr.; 850°F., 1 hr.	249,000	111	175	281,000	125·5	198	13	61	273,000	122	192	0·97
1500°F., 1 hr.; cold-reduced 50%; 850°F., 1 hr.	254,000	113·5	179	280,000	125	197	13	61	364,000	162·5	256	1·30

* All notched tensile data were obtained on specimens with a parallel section diameter of 0·300 in. (0·75 cm.) and a 60° circumferential notch at midlength. Root radius of the notch was 0·0006 in. (0·015 mm.), depth about 0·045 in. (1·125 mm.). This gave a stress concentration factor, K, of 10. † Annealed hardness: Rockwell C-25. ‡ Annealed hardness: Rockwell C-15.

in the present paper, tempering in a 1·14 per cent. plain-carbon steel, and in five 1 per cent. carbon steels containing alloying additions of, respectively, silicon, manganese, nickel, chromium and molybdenum, was studied over the range 23°–100°C. by measurements of change in electrical resistivity.

The resistance of the chromium and molybdenum steels decreased continuously with tempering time at all temperatures, but the resistance changes in the silicon, nickel and plain-carbon steels exhibited a positive peak, and those of the manganese steel a point of inflection, at temperatures below 80°C. These variations in resistance are considered to be associated with the effect of the alloying elements on the precipitation of ε-carbide in coherent form.

The activation energy of the first stage of tempering had a unique value for each of the steels studied, but the values obtained for the alloy steels did not conform to the linear relationship between activation energy and carbon content previously established for plain-carbon steels. Silicon and nickel increased the activation energy, while chromium, manganese and molybdenum lowered it, results which are discussed in terms of the influence of the alloying elements on the behaviour of the carbon in solution in the martensite.

25% Nickel Age-Hardenable Steels for High-Strength Applications

'Progress with 25% Nickel Steels for High-Strength Applications.'

Metal Progress, 1960, vol. 78, Nov., pp. 99–100.

Work on the evaluation of experimental high-strength low-carbon (<0·05 per cent.) nickel steels has been in progress for some time at the Bayonne Research Laboratory of The International Nickel Company, Inc. Nickel content varies from 18 to 27 per cent., and the steels are rendered age-hardenable by controlled additions of titanium and aluminium. When annealed, air-cooled and aged, they respond to combined precipitation and transformation hardening. The data presented in this article are based on laboratory heats, and the evaluation programme is continuing.

Heat-treatments for, and data on, the tensile properties of steels of 20 and 25 per cent. nickel type are discussed. Cold-working properties are stated to be good; weldability studies are in progress. Preliminary investigations show that heat-treated steels containing 25 per cent. nickel, and a combined aluminium and titanium content of 6–8 per cent., develop a hardness of Rockwell C66–67.

A table indicating heat-treatments for, and typical tensile properties of, 25 per cent. nickel steels is reproduced above.

Tensile Strength and Hardness of Nickel-Chromium-Molybdenum Steel at Low Temperatures

J. NUNES and F. R. LARSON: 'Low-Temperature Tensile-Hardness Correlations for S.A.E. 4340 Steel.'

Amer. Soc. Testing Materials Bull., 1960, Oct., pp. 25–9.

The information presented has been previously published in the form of a technical report: see abstract in *Nickel Bulletin*, 1960, vol. 33, No. 12, pp. 309–10.

Low-Temperature Properties of Nickel-containing Steels

See abstract on p. 47.

Use of Steel Castings in Aeronautical Applications

J. VARGA: 'A Review of Certain Ferrous Castings Applications in Aircraft and Missiles.'

Defense Metals Information Center, Battelle Memorial Inst., Report 120, Dec. 18, 1959; 50 pp.

Steel castings can be used to advantage in many aeronautical applications, but the unsatisfactory performances of some castings in the past has tended to make the aircraft designer hesitant to use them. In the light of the insufficient understanding deemed to obtain between founder and aircraft designer, this report was published to describe 'the types of casting that have been made in the past, those that are being made, and the trend of possible casting requirements for future aircraft'.

The types of casting employed in aeronautical applications (including those cast in nickel-containing steel) are discussed in sections concerned with engine castings, miscellaneous castings, castings for ground-support equipment, and primary-airframe castings. Typical applications are illustrated in a series of photographs of actual cast equipment. Four main requirements are stipulated by the aircraft designer: (1) accuracy and precision of configuration; (2) inherent quality; (3) ability to perform the desired function; and (4) reliability of delivery. In the final section of the report, these requirements are considered in relation to the rôle of designer and foundryman.

Recent Developments in Metal Working

See abstract on p. 43.

Milling of High-Strength Steels

C. T. OLOFSON: 'Milling of High-Strength Steels in the Hardness Range of 330 to 560 Brinell.'

Defense Metals Information Center, Battelle Memorial Inst., Memorandum 30, Aug. 17, 1959; 21 pp. + appendix.

In this report, which is based on a *bibliography* of 30 items, the author has collated the information and data available on the face milling, end milling and slotting of steels at hardness levels up to 560 Brinell.

Recommendations are made with respect to: milling machines; power requirements; vibration effects; tool and work rigidity; cutter requirements (e.g., tool geometry); milling set-up; face-milling, end-milling and peripheral-milling operations. Tool life is lengthened and the production rate higher, if, throughout cutting, the machine tool and workpiece are maintained rigid, and adequate power is available to maintain the cutting speed. Equally important, however, is the selection of feeds, speeds and depths of cut appropriate to the recommended tool materials and designs. In an appendix to the memorandum, the tool materials employed for milling cutters are referred to in sections covering carbides, cast cobalt-chromium-tungsten alloys, and high-speed steels. The appendix includes a nomograph for determining horsepower requirements when milling high-strength steels at various hardnesses.

Comparison of Notch-Toughness Tests for Welded Steel

H. H. JOHNSON and R. D. STOUT: 'Comparison and Analysis of Notch-Toughness Tests for Steels in Welded Structures.'

Welding Research Council, Bull. 62, July 1960; 28 pp.

This report, in which reference is made to a *bibliography* of 37 items, comprises an interpretive survey of the literature on the notch-toughness of steels used in welded structures. It is not intended to review the entire field of brittle fracture, but rather to focus attention upon the significance of different laboratory notch-toughness tests and to discuss data recently available.

The bulletin is in three main sections. The first is concerned with the broad background against which any analysis of notch-toughness tests must take place. The rôle of service experience in the evaluation of laboratory tests is discussed, significant notch-toughness tests are described and typical data presented, and consideration is given to the criteria to be employed in evaluating tests results.

In the second section, the authors discuss tests which have been employed to measure the ductility transition temperature of plain-carbon steels, and take into account correlation of results, sensitivity to compositional and processing variables, and significance for service performance.

The third section comprises a critical review of the data and information presented in the first two. Summarizing their findings, the authors conclude that the different notch-toughness tests generally show a statistical agreement in reflecting the influence of steel composition, deoxidation practice, chemical composition, heat-treatment, etc. Significant scatter is, however, frequently present, and these statistical correlations are therefore of limited use in predicting transition temperatures in one test from data obtained experimentally with another.

A condensed version of the report has been published in *Welding Journal*, 1960, vol. 39, Nov., pp. 493s–501s.

Welding Nickel-Steel Components of Radar Equipment for Arctic Service

W. R. SCHNEIDER: 'Quality Control is a Must When Welding Radar Antennas.'

Welding Engineer, 1960, vol. 45, Sept., pp. 58–60.

In the design and fabrication of radar antennas for Arctic service, D. S. Kennedy & Company, Chasset,

Mass., were confronted not only with the task of assembling more than 1 million parts (weighing 10½ million lb. and involving 168,000 ft. of welding), but also with the difficulty of erecting the unit in an area where there was little or no equipment for field welding.

Two grades of steel were selected for use in the structural members of the antennas: *A.S.T.M.* 203 *Grade D* (3½ per cent. nickel), and *Grade A*, modified (2¼ per cent. nickel). The welding of radar equipment for such low-temperature service requires close co-ordination and control of basis materials, filler metals, design, welding processes, and testing. Each of these factors is discussed in the present article, and details are given of the welding procedures finally evolved.

Welding of Low-Alloy Steel for Bridges

J. L. BEATON and P. G. JONAS: 'Welding of High-Strength Low-Alloy Structural Steel for Bridges.'

Welding Jnl., 1960, vol. 39, Nov., pp. 1117–23.

In California, bridge designers nowadays utilize low-alloy high-strength steel in well over half their designs, and practically all the highway bridges constructed by the California Division of Highways are of welded fabrication.

Two grades of high-strength steels have been used in these welded structures: weldable steels conforming to *A.S.T.M. A242*, and the complex nickel-chromium-molybdenum-vanadium steel 'T-1'. Some of the major bridges incorporating these steels form the subjects of the initial part of the article (approximately 3,000 tons of 'T-1' steel, 5,000 tons of A242 steel, and 6,000 tons of A373 steel were used, for example, in the construction of the Carquinez Bridge near San Francisco). Subsequent sections are concerned with the factors involved in the welding of high-strength low-alloy steels.

Welding of High-Strength-Steel Sheet for Rocket Cases

W. H. KEARNS, J. W. SEMMEL and J. D. MARBLE: 'Welding of High-Strength Steels for Rocket Cases.'

Welding Jnl., 1960, vol. 39, Nov., pp. 484s–92s.

Various ultra-high-strength steels are (on account of their high strength/weight ratio) being used, or considered for use, as materials for the rocket cases of solid-propellant intercontinental ballistic missiles. Weldability is a prime factor governing the suitability of a specific steel for such applications, and since steels of this type (steels of modified A.I.S.I. 4340 grade form the subjects of the present article) contain 0·4 per cent. or more carbon, the production of sound welds, with adequate ductility, strength and notch toughness, entails the use of special welding techniques. In this paper the authors report the results of a study of the weldability of three typical high-strength steels: the 2%Ni–0·75%Cr steel '300M'; the 2%Cr steel 'X-200'; and the 1%Cr–1%Mo–0·5%Ni steel 'D6A'. Details are given of the procedures evolved for the production (using the inert-gas-shielded tungsten-arc welding process) of sound weldments in the three steels, the preheating and postheating procedures established, and the development of a special ceramic backing bar to avoid weld cracking.

Filler-wire compositions and heat-treatments for the three steels were evaluated by metallographic studies and determination of mechanical properties, and the special heat-treatment developed to reduce the prior austenitic grain-size in the welds is discussed. Improved weld-joint ductility and notch toughness were found to be obtained by use of low-carbon filler wires and/or the grain-refining heat-treatment. For the severest service conditions the authors recommend the use of both low-carbon filler wire and grain refinement.

Fabrication of Low-Alloy-Steel Impeller Wheels by Welding

J. H. MATHENY and E. L. AUL: 'Welding Centrifugal-Compressor Impeller Wheels.'

Welding Jnl., 1960, vol. 39, Nov., pp. 1127–35.

The impeller wheels to which the article relates were designed for use in centrifugal compressors in a 24-in. (60-cm.) gas-transmission line. Originally the 36-in. (90-cm.) diameter impeller was of milled and riveted construction, but when the need arose to increase the volume of gas handled, without resorting to major changes in design, it was decided to join the component parts by welding, and so take advantage of the higher operating speeds permissible for welded impellers. Service requirements entailed the use of a high-strength steel which would both possess the necessary mechanical properties and be readily fabricated by means of the facilities available, and, in view of its satisfactory performance when used in the mechanically-joined impellers, the choice finally fell upon A.I.S.I. 4340 nickel-chromium-molybdenum low-alloy steel.

In this paper, the authors give full particulars of the procedures employed in the fabrication of the impeller. The information is presented in sections concerned with: joint design, welding equipment, welding procedures, heat-treatment, tooling, assembly and welding, welding inspection and repair, and final machining and balancing.

HEAT- AND CORROSION-RESISTING MATERIALS

Thermal and Electrical Conductivities of 'Nimonic' Alloys

HENRY WIGGIN AND COMPANY, LTD.: 'Thermal and Electrical Conductivities of the 'Nimonic' Heat-Resisting Alloys.'

Publication 2181, 1960; 7 pp.

The publication is based on an article by R. W.

POWELL and R. P. TYE which appeared in *Engineer*, 1960, vol. 209, Apr. 29, pp. 729–32: see abstract in *Nickel Bulletin*, 1960, vol. 33, No. 8–9, pp. 208–9.

Short-Time Properties of '17-7 P.H.' and 'N-155' at Elevated Temperatures

E. C. BERNETT: 'Short-Time Elevated-Temperature Stress-Strain Behaviour of Tensile, Compressive and Column Members.'

Wright Air Development Center, Tech. Report 59–484, Dec. 1959; 131 pp.

In many aeronautical applications involving high operating temperatures, the service life of the material of construction is very brief (in the region of a few minutes). To determine the maximum conditions which relevant structural materials can withstand during such short-time service, tests have been devised which closely simulate operational conditions (high rates of heating, high terminal temperatures, rapid rates of loading, and very high levels of stress). The investigation now reported was initiated to evaluate the behaviour of the following four aircraft structural materials (in the form of sheet) when exposed to compressive stresses at low and high temperatures: an aluminium alloy (aged), a titanium alloy (annealed), the chromium-nickel steel '17-7 P.H.' (aged), and the iron-chromium-nickel-cobalt-base alloy 'N-155' (annealed).

The materials were subjected to tensile tests, compression tests, compression-creep tests, and (in the case of the aluminium alloy) compression tests on column members. Account was taken of the effects of heating rate, holding time at temperature, and rate of loading. The tests were carried out at temperatures up to 2000°F. (1095°C.), at holding times of 2 or 30 minutes and strain rates ranging from 0·00001 to 0·1 in./in./sec. In the elevated-temperature tests the specimens were heated at a nominal rate of 200F.°/second.

The significance of the data obtained is discussed in relation to the behaviour of columns subjected to high temperatures and stresses. Changes in testing speed were found to result in wide variations in tensile and compressive strengths, particularly at elevated temperatures. It is also demonstrated that time-dependent deformation rates at high stresses and temperatures are very rapid. Large amounts of plastic strain can occur, even when the time involved is of the order of 1 second or less.

Surface Films on Bright-Annealed Stainless Steels

J. H. WAXWEILER: 'Surface Films on Annealed Stainless Steels.'

Metal Progress, 1960, vol. 78, Sept., pp. 80–3.

Though both hydrogen and dissociated ammonia have been used successfully as protective atmospheres in bright annealing stainless steels, the latter environment cannot be used with either 'Armco 17-7 P.H.' or 'P.H. 15-7 Mo' stainless steels because of the danger of their being nitrided. When bright annealing is carried out in hydrogen with a dew point of −25°F. (−30°C.) or higher, the steel strip has a definite blue appearance, and visual inspection is sufficient to distinguish it from strip which has been bright-annealed correctly. This observation led to an investigation which, initiated to obtain information on the variation in the colour characteristics of the surface with variation in the dew point of the environment, is described in the present article.

'17-7 P.H.' foil 0·0015 in. (0·0375 mm.) thick, in the cold-reduced condition and originating in two heats of steel, was annealed at 1950°F. (1065°C.) in a hydrogen atmosphere, and the colour and reflectivity of the strip was studied as a function of variation in the dew point.

As the dew point was raised from −85°F. to −41°F. (−65°C. to −40°C.), only one change in surface colour was observed, the film becoming more yellow. As the dew point was raised to −36°F. (−38°C.) and −30°F. (−34°C.), however, the surface films changed colour, first adding a small amount of red and then a large amount of blue. The results from the reflectivity tests were in agreement with those from the colour tests, the highest reflectivity value being exhibited by the whitest sample, and reflectivity decreasing with increase in the dew point.

Surface films on specimens of '17-7 P.H.' and 'P.H. 15-7 Mo' foil were subjected to examination by electron-diffraction techniques. The data obtained indicate that a surface film of aluminium and chromium oxides was present on the specimen bright-annealed at the lowest dew point employed. As the dew point was increased, the amount of chromium oxide relative to the amount of aluminium oxide also increased, until the latter constituent could no longer be identified in the surface film (dew point −30°F.: −34°C.), probably as a result of being masked by the much larger quantity of chromium oxide.

25% Nickel Age-Hardenable Steels for High-Strength Applications

See abstract on p. 37.

Mechanical Properties of Aluminium-Iron-Nickel Sintered Materials

P. LELONG, J. MOISAN and J. HÉRENGUEL: 'Mechanical Properties (Tensile) of Sintered Aluminium Structures with Additions of Iron and Nickel (in the Worked Condition) (for Resistance to Corrosion by High-Temperature Water).'

Mémoires Scientifiques de la Revue de Métallurgie, 1960, vol. 57, Sept., pp. 683–8.

In the investigation described, which was intended to provide data supplementing those available on the resistance of sintered aluminium-iron-nickel alloys to high-temperature water, specimens were subjected to mechanical tests at 25° and 350°C. The nickel (1 per cent.) and iron (1 or 2 per cent.) were introduced either in oxide form or in the form of an intermetallic compound. The materials were produced by sintering/extrusion, followed, in some cases, by hot rolling.

In determining the ultimate tensile strength, proof stress and elongation at rupture, account was taken of the influence of the following factors: the particle size of the aluminium powder; the production method; the presence of Al_2O_3; and composition. Addition of iron and nickel, which previous investigations had shown to enhance corrosion-resistance in high-temperature water, resulted in a slight improvement in mechanical properties (the ultimate strength being increased and elongation at rupture lowered). The results indicate, however, that the mechanical properties were governed predominantly by the classical aluminium/alumina structure of the materials.

High-Temperature Oxidation of Nickel-Cobalt Alloys

K. FUEKI and A. FURUKAWA: 'A Study of High-Temperature Oxidation of Nickel-Cobalt Alloys.'

Jnl. Chemical Soc. Japan, Industrial Chemistry Sectn., 1960, vol. 63, May, pp. 724-29.
English abstract, p. A38.

The investigation described was undertaken in an attempt to throw light on the oxidation behaviour of binary alloys, in particular, nickel-cobalt alloys. Nickel, cobalt, and five nickel-cobalt alloys containing 4·9, 11·3, 22, 38·1 and 60·7 mole per cent. of cobalt were selected for study. The investigation involved the following five phases:

1. *Determination of Oxidation Rates*

Using a vacuum microbalance, oxidation rates were established, under an oxygen pressure of 10 mm. of mercury, at temperatures in the range 650°-850°C. All the specimens were found to oxidize parabolically. Parabolic rate constants were derived from the parabolic plots, and the law $W^2 = k_p t + C$ was found to hold. The activation energies were determined from the Arrhenius plots.

2. *Microscopical Study*

Microscopical examination of the oxide films showed them to consist of a single homogeneous layer.

3. *X-Ray Study of the Oxide Films*

Study of the films, using X-ray-diffraction techniques, revealed the presence of the solid solutions of NiO and CoO in all the alloys. In the case of the 60·7 per cent. cobalt alloy, Co_3O_4 was also found.

4. *X-Ray Study of the Surface of the Oxidized Alloys*

The change in composition of the alloy surfaces as a result of oxidation was investigated by measurement of lattice parameters. No change was found in those alloys containing 4·9, 11·3 and 20 per cent. cobalt, but the remaining two alloys were slightly enriched in nickel.

5. *Chemical Analysis of the Oxide Films*

Oxide films stripped from the basis alloys were analyzed by the polarographic method. The mole per cent. of cobalt in the oxide was found to equal that in the original alloy.

The oxidation behaviour of the nickel-cobalt alloys is discussed by the authors on the basis of the data obtained.

Internal Carburization and Oxidation of Nickel-Chromium Alloys in Carbon-Monoxide Atmospheres

B. E. HOPKINSON and H. R. COPSON: 'Internal Carburization and Oxidation of Nickel-Chromium Alloys in Carbon-Monoxide-Type Atmospheres.'

Corrosion, 1960, vol. 16, Dec., pp. 608t-12t.

Internal oxidation of nickel-chromium alloys has been the subject of several laboratory investigations. Some workers have regarded carburization as a prerequisite stage to internal oxidation; others consider carburization irrelevant, and postulate that the basic internal-oxidation reaction occurs at oxygen pressures low enough to oxidize the chromium and to leave the nickel in metallic form. In previous work COPSON and LANG had produced internal oxidation in nickel-chromium alloys by exposing them to carbon monoxide at elevated temperatures (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 7, pp. 227-8). The study now reported was undertaken to determine the effects, on the internal oxidation of the same types of alloy, of (1) introducing other gases into the carbon-monoxide test atmosphere, (2) temperature, (3) alloying additions of niobium, titanium and silicon. The compositions of the alloys tested are tabulated below.

The tests were run for 7 days in four types of atmosphere: CP carbon monoxide; commercial carbon

Analysis of Materials
(See abstract above)

Ni %	Cr %	Fe %	C %	Si %	Mn %	Ti %	Al %	Nb + Ta %
Bal	3·9	0·10	0·03	0·46	0·01	0·13	0·06	—
Bal	13·53	0·13	0·02	0·45	0·01	0·08	0·01	—
Bal	19·77	0·10	<0·01	0·52	0·01	0·10	0·02	—
Bal	21·74	0·51	0·03	0·42	0·25	0·03	<0·01	—
Bal	14·10	5·61	0·04	0·48	0·85	0·13	0·03	—
Bal	13·49	5·83	0·05	0·49	0·78	0·11	0·03	—
Bal	14·19	20·25	0·03	0·45	0·78	0·11	0·03	—
Bal	15·88	5·63	0·02	1·34	0·84	0·07	0·03	—
Bal	15·83	6·91	0·03	0·29	0·18	0·31	0·22	1·96
Bal	15·80	7·68	0·05	0·28	0·34	0·28	0·12	—

monoxide; CP carbon monoxide+hydrogen; and CP carbon monoxide+carbon dioxide. The effects of water vapour were established by saturating the gases with moisture at room temperature before testing. The influence of temperature was studied over the range 1330°–1830°F. (720°–1000°C.). At the end of a run, changes in weight, temperature and magnetic properties were noted, and the depth of internal oxidation and carburization was measured. Surface oxides were subjected to examination by X-ray-diffraction techniques.

The data presented by the authors show that in dry CP carbon monoxide the rate of internal carburization and oxidation attained a maximum in the range 1500°–1750°F. (815°–955°C.); at 1330°F. (720°C.) and at 1830°F. (1000°C.) attack was slight. The presence of carbon dioxide, water vapour or hydrogen was not found significantly to affect the rate of penetration in the carbon-monoxide atmosphere. The results of electron-probe microanalysis revealed the chromium content of the oxides and carbides present in the alloys after testing to be higher than that in the matrix phase.

In discussing the mechanism of internal oxidation the authors allude to the fact that the decomposition of carbon monoxide decreased fairly rapidly with temperature. It is suggested therefore that optimum conditions for internal oxidation are associated with the formation of a gas mixture containing between 3 and 13 per cent. carbon dioxide. When the dissociation of carbon monoxide to form more than 1 per cent. carbon dioxide is impossible, internal oxidation becomes negligible. The significance of catalytic effects and the rôle of carbon are also discussed.

The results throw some light on the relationship between the various alloying elements and the resistance of the alloys to internal oxidation. The chromium level did not seem to be significant in relation to the depth of oxidation, and the 20, 14 and 4 per cent. chromium-nickel alloys exhibited approximately the same depth of penetration under all conditions. The 20 and 14 per cent. chromium alloys were subjected to the same degree of carburization, but, in the case of the 4 per cent. chromium alloy, no carburization preceding oxidation was observed under any of the conditions.

At chromium contents of 20 and 14 per cent., attack was uniform, with no tendency to preferential attack at the grain boundaries. Attack on the 4 per cent. chromium alloy was generally intergranular.

In the case of the 14 per cent. chromium alloy, an alloying addition of 6 per cent. iron had no pronounced effect on the depth of oxidation or carburization in most of the environments: the hydrogen/carbon-monoxide environment was the only one in which the addition appeared to influence the reaction, the depth of oxidation being reduced. Increase in the iron content from 6 to 20 per cent. tended to increase carburization and oxidation at 1830°F. (1000°C.) in dry CP carbon monoxide, though this increased carburization and oxidation was not observed when the gas was saturated with water vapour.

Addition of 1·3 per cent. silicon to the 14 chromium–6 iron–nickel alloy significantly reduced, but did not grant immunity to, attack.

Two alloys of modified 'Inconel' type (the last two in the table) showed no evidence of carburization or oxidation under any of the test conditions.

High-Temperature Corrosion in Refinery Service

E. N. SKINNER, J. F. MASON and J. J. MORAN: 'High-Temperature Corrosion in Refinery and Petrochemical Service.'

Corrosion, 1960, vol. 16, Dec., pp. 593t–600t.

This paper was originally presented at the 16th Annual Conference of the National Association of Corrosion Engineers, Dallas, 1960, and has been abstracted, from the preprint then available, in *Nickel Bulletin*, 1960, vol. 33, No. 7, p. 179.

Heat-Affected-Zone Cracking in 18-12-Nb Weldments: Microstructural Study

N. E. MOORE and J. A. GRIFFITHS: 'Microstructural Causes of Heat-Affected-Zone Cracking in Heavy-Section 18-12-Nb Austenitic Stainless-Steel Welded Joints.'

Jnl. Iron and Steel Inst., 1961, vol. 197, Jan., pp. 29–39.

The widespread difficulties associated with the susceptibility of weldments in 18-12-Nb (Type 347) austenitic stainless steel to heat-affected-zone cracking have led to numerous investigations, including that by TRUMAN and KIRKBY (*see* abstract in *Nickel Bulletin*, 1960, vol. 33, No. 12, p. 323) which indicated that cracking could be related to abnormally low hot-ductility values resulting from certain temperature and strain conditions (such as may obtain in the heat-affected zone of the basis metal close to the weld). In the work reported by the present authors an electron-microscopical study was made of the structures developed in test specimens provided by TRUMAN and KIRKBY.

To simulate the effect of the high temperatures attained in the heat-affected zone of weldments, specimens of ½-in. (1·25-cm.) diameter bar were solution-treated 1 hour at 1050°C. (with air cooling), followed by further solution-treatment for 3 minutes at 1350°C. Tensile tests were carried out at temperatures in the range 650°–1200°C., and specimens were then subjected to examination by optical and electron microscopy. Photomicrographs illustrate the points raised in the authors' discussion of the results of the investigation.

The pronounced changes in the ductility of 18-12-Nb steel found by TRUMAN and KIRKBY in hot tensile tests in the range 650°–1200°C. (the specimens had been previously treated at 1350°C.) are attributed to changes in microstructure. The effect of ageing at 850°C., after the high-temperature treatment and before hot-tensile testing, is also accounted for on the same basis.

The microstructural changes which govern ductility on hot tensile testing are listed as: (1) grain

coarsening at 1350°C.; (2) precipitation of a network of chromium carbides of the $M_{23}C_6$ type at the grain boundaries; (3) precipitation of niobium carbide as discrete particles within the crystals in the absence of plastic strain; (4) precipitation of niobium carbide within the crystals in a thread-like form on dislocations associated with the 111 slip planes (a strain-induced effect which can occur, at temperatures in the region of 850°C., in the presence of a strain below 0·01, and which appears to have a marked stiffening effect due to dislocation locking); (5) the combination of carbon with chromium, to form more grain-boundary carbide in preference to niobium carbide within the grains, thus giving rise to denuded zones adjacent to the grain boundaries. These structural changes are correlated with ductility.

It is suggested that similar metallographic changes occur in the heat-affected zone of welded joints and may reduce the ductility to a degree permitting cracking under the influence of contraction stresses, either during cooling after welding, during stress-relieving treatment, or, possibly, during service. The microstructural changes causing embrittlement in the 18-12 steel were not observed in comparative tests with a steel of 17-11-Mo type.

Tensile/Impact Test for Determination of Hot-Working Temperatures

'Tensile-Impact Test Reveals Best Hot-Working Temperature.'

Metal Progress, 1960, vol. 78, Oct., pp. 65-6.

The hot working of many alloys intended for high-temperature applications has proved difficult because of the narrow range in which the operation must be carried out. To establish optimum working temperatures, metallurgists at Carpenter Steel Company suggest the use of a tensile/impact test in which data on impact strength, elongation and reduction-in-area are obtained, over a range of temperatures, by breaking hot specimens in a modified Sonntag universal impact machine. The specimens are held at the desired temperature for a minimum of 30 minutes, and then placed in the testing machine and broken within 4 seconds. Plotted as a function of temperature, the tensile/impact properties indicate the hot working range of the alloy.

In this note, data on 'Carpenter V-57'* show that impact energy, elongation and reduction-in-area decrease markedly just above the maximum permissible hot-working temperature. At the lower limit of the range, the properties again decrease, but not as abruptly.

Determination of Stress-Relief Temperatures by the Hindered-Thermal-Contraction Technique

H. S. AVERY: 'Temperatures for Rapid Uniaxial Stress Relief of Heat-Resistant Alloys.'

Welding Jnl., 1960, vol. 39, Nov., pp. 509s-12s.

The hot-test technique described is stated to provide a means of selecting a suitable temperature for rapid stress relief of heat-resisting alloys which is both quicker and less costly than strain-gauge measurements of residual stress or determination of time/temperature variables. The test may be carried out on any tensile machine equipped with a furnace for specimen heating.

By heating a specimen to a high temperature in a tensile machine, applying a small load to remove any slack in the system, and then slowly cooling the test bar, the unrelieved stress characteristics at each temperature are reproduced on the load indicator of the machine and can be plotted. In parallel experiments the author found that, by arresting cooling at some temperature, and by applying an additional load, the increased stresses were, within a few minutes, reduced by flow to values corresponding to the temperatures plotted, but stress-decrease thereafter was scarcely perceptible. The graph portraying the trend encountered reveals the level to which stress must fall at a given temperature: a higher stress will promptly cause plastic flow. As the specimen is cooled and contraction occurs, there is a continuous increase in stress and an associated flow that relieves this stress beyond a critical level. The cumulative flow is reflected by the elongation and reduction-in-area at room temperature. The specimen may break during this treatment, but ductile metals can undergo several such hindered-contraction cycles without failure.

The application of the test is exemplified in the paper in relation to data presented on a range of cast chromium-nickel heat-resisting steels.

Comparison of Notch-Toughness Tests for Welded Steel

See abstract on p. 38.

Recent Developments in Metal Working, High-Temperature Materials and Non-Ferrous Alloys

Metal Progress, 1960, vol. 78, Oct., contains a 'Special Report for Technical Management in Metal Working, High-Temperature Materials and Non-Ferrous Alloys', comprising a series of review articles, the scope of which is briefly noted below. Many of the alloys and low- and high-alloy steels referred to are nickel-containing.

'How to Get More from Modern Steels', pp. 71-83.

The review covers recent progress in, and the potentialities of, low-alloy high-strength steels, leaded steels, cold-extruded steels, 25 per cent. nickel precipitation-hardenable steels, vacuum-processed steels, steels for aeronautical forgings, steels for use in nuclear-power plant, and galvanized sheet.

Brief separate articles give information on new concepts in the drawability of steels (R. L. WHITELEY and D. J. BLICKWEDE, pp. 74-5), progress in cold-heading (p. 77), and advances in chromium-nickel stainless steels (pp. 81-3).

* Composition: carbon 0·05, chromium 14, nickel 26·5, molybdenum 1·5, titanium 3·0, aluminium 0·25, boron 0·007, per cent.

P. G. NELSON: 'Progress in Forming Steels: How to Make Better Drawings and Stampings', pp. 85–95.

R. A. WILSON: 'Progress in Welding Steels: Vapour-Shielded Arc Means Faster Welding', pp. 96–9, 152, 154.

The author gives details of a new welding process ('Innershield'), which, developed by Lincoln Electric Company, employs vapour (rather than gas) shielding. The shielding is formed by the vaporization, during welding, of metallic oxides and salts incorporated in the cored-wire electrode used.

'Modern Quenching Techniques Make it Easier to Heat-Treat Steel', pp. 101–13.

Use of the proper quenchent enables most steels (ranging from plain-carbon to the stainless grades) to be quenched with little danger of cracking or warping. This article outlines the salient characteristics of the various quenching media employed and discusses relevant equipment.

This section of the review includes notes on 'Automatic Quenching of Ring Gears' (pp. 106–7) and 'Measuring Quenching Rates with the Electronic Quenchometer' (H. J. GILLILAND, pp. 111–13).

M. F. GARWOOD: 'Materials and Process Applications in the Automotive Industry', pp. 115–29.

The review covers trends in aluminium die castings, pearlitic malleable iron, low-alloy steels, aluminized valves, powder-metallurgically produced parts, cold extrusion of steels, protection against corrosion, use of duplex-nickel deposits for bright trim, paint finishes, and use of plastics.

E. S. JONES and L. P. JAHNKE: 'Updating High-Temperature Metallurgy', pp. 130–5.

Developments in the field of high-temperature metallurgy are discussed in relation to: 'Ausforming' of martensitic steels; titanium alloys; cold-worked nickel-base high-temperature alloys; nickel-cobalt high-temperature alloys; niobium alloys; tungsten.

'Progress in Aluminium Alloys', pp. 136–42.

'Progress in Copper Alloys', pp. 143–5, 154, 156, 158.

J. V. WINKLER: 'Progress in Magnesium Alloys', pp. 146–8, 158, 160.

'Astroloy': Properties, Heat-Treatment and Fabrication

J. F. BARKER, W. H. COUTS and R. J. MORRIS: "Astroloy"—a Superalloy for 1900°F. Use.'

Metal Progress, 1960, vol. 78, Dec., pp. 94–7.

The vacuum-melted age-hardenable nickel-base high-temperature alloy 'Astroloy' was developed by the Flight Propulsion Division of General Electric Company for use in jet-engine components required to operate for long periods under substantial loads in oxidizing environments at 1800°–2000°F. (980°–1095°C.). In this article the authors discuss the factors involved in the development of the alloy and give details of the heat-treatments evolved and the properties to which they give rise.

Attention is briefly drawn to the studies which led up to the establishment of the final alloy composition: chromium 15, cobalt 15, molybdenum 5, aluminium 4·5, titanium 3·5, carbon 0·5, silicon 0·05, manganese 0·05, boron 0·03, per cent., remainder nickel. The procedures involved in rolling the alloys to sheet are then considered, and reference is made to the optimum heat-treatments developed. The annealing cycle entails holding at 2100°F. (1150°C.) for 30 minutes, air cooling, holding at 2000°F. (1095°C.) for 15 minutes, and water quenching. Maximum creep-rupture strength in the range 1400°–1800°F. (760°–980°C.) is obtained by subjecting the sheet to solution-treatment at 2100°F. (1150°C.) for 30 minutes, air cooling, ageing at 1650°F. (900°C.) for 4 hours, and air cooling: properties resulting from subjecting 0·06-in. (1·5-mm.) sheet to this treatment are noted below.

Tensile Properties	Room Temperature	1400°F.: 760°C.
Tensile Strength	194,000 p.s.i. 86·5 t.s.i. 136·5 kg./mm.²	155,000 p.s.i. 69 t.s.i. 109 kg./mm.²
0·2% Yield	142,000 p.s.i. 63·5 t.s.i. 100 kg./mm.²	139,000 p.s.i. 62 t.s.i. 98 kg./mm.²
Elongation	15·0 per cent.	6·0 per cent.
Stress-Rupture Properties	1650°F.: 900°C.	1800°F.: 980°C.
Stress	27,000 p.s.i. 12 t.s.i. 19 kg./mm.²	18,000 p.s.i. 8 t.s.i. 12·5 kg./mm.²
Time-to-failure	177·0 hours	50·7 hours
Elongation	8·0 per cent.	7·0 per cent.

Data presented indicate that thermal cycling between 1350° and 1875°F. (735° and 1020°C.) is not detrimental to tensile strength, rupture life, or ductility.

The paper ends with an allusion to the properties obtainable in investment castings, and with an outline of the microstructural features of the alloy.

Fabrication of 'René 41'

L. A. WEISENBERG and R. J. MORRIS: 'How to Fabricate 'René 41'.'

Metal Progress, 1960, vol. 78, Nov., pp. 70–4.

In this article the authors discuss the procedures

Brazing Alloys for 'René 41'

(See abstract below)

Alloy	Composition						Brazing Temperature		Brazing Atmosphere	Service Temperature	
	Ni %	Cr %	Pd %	Si %	Cu %	In %	°F.	°C.		°F.	°C.
'J-8600'	39	33	24	4			2150	1175	Vacuum	1500	815
'J-8100'	71	19		10			2200	1205	Hydrogen*	1900	1035
'J-8500'	35				60	5	2200	1205	Hydrogen*	1400	760

* Basis metal must be nickel-plated.

which research has shown to be optimum in heat-treating, welding and brazing 'René 41'*, an age-hardenable austenitic turbine-blading alloy developed by General Electric Corporation.

Two heat-treatments have been devised for 'René 41': the first, which confers maximum tensile properties, involves solution-treatment at 1950°F. (1065°C.) for 30 minutes, air-cool, and ageing treatment for 16 hours at 1400°F. (760°C.); the second, employed if optimum stress-rupture properties are desired, involves solution-treatment at 2150°F. (1175°C.) for 30 minutes, air-cool, and ageing for 4 hours at 1650°F. (900°C.).

Experience in welding the alloy is summarized by the authors as follows:

'1. 'René 41' must be in the 1975°F. (1075°C.) mill-annealed condition prior to forming or welding.

'2. Welding of cold-worked parts should be avoided. Any necessary in-process anneals should be a 1975°F. treatment followed by a rapid quench.

'3. Strain age cracking can be avoided by charging welded components into a hot furnace (1970°F. minimum) to reach the solution-temperature as rapidly as possible. This minimizes the time in the ageing range.

'4. Weld designs and procedures that minimize weld restraint and heat input are most important for the consistent fabrication of good parts.

'5. The preferred inert-arc filler materials for high-strength weldments are 'Hastelloy W' and 'Hastelloy X'.'

See also

Brazing of 'René 41'

G. S. HOPPIN: 'Brazing of 'René 41'.'

Metal Progress, 1960, vol. 78, Nov., pp. 75–9.

The investigation described culminated in the determination of three brazing alloys suitable for use in brazing 'René 41'*. In presenting the findings of this work, the author takes into account the significance of such factors as the brazing atmosphere, the solidus and liquidus temperatures of the brazing alloy, the melting point and heat-treatment of the basis metal, the service temperature of the component, reactions between the brazing alloy and the basis metal, and the size of the gaps to be filled by the brazing alloy.

The compositions of the three brazing alloys found most suitable are noted in the table above.

Commercial brazing alloys high in boron or silicon were found to embrittle the basis alloy. Alloy 'J-8100' was shown to be suitable as a brazing material, provided the basis metal was nickel plated prior to brazing, and alloy 'J-8500' is also considered a satisfactory wide-gap brazing alloy for use with nickel-plated 'René 41'. The new nickel-chromium-palladium-silicon alloy 'J-8600' is regarded as an excellent vacuum-brazing alloy, and is recommended as the best means of brazing 'René 41'.

Mechanical tests on brazed specimens subjected to the recommended post-brazing heat-treatment [solution-treatment at 1950°F. (1065°C.) followed by ageing at 1400°F. (760°C.)] revealed that tensile and yield strengths were decreased only about 10 per cent. as a result of brazing.

* Nominal composition: chromium 19, cobalt 11, molybdenum 9·75, titanium 3·15, aluminium 1·5, boron 0·006, iron 0·5, carbon 0·08, per cent., remainder nickel.

Milling of High-Strength Steels

See abstract on p. 38.

Welding of 'Inconel' for Nuclear-Power Applications

C. E. WITHERELL: 'Welding of Nickel-Chromium-Iron Alloy for Nuclear-Power Stations.'

Welding Jnl., 1960, vol. 39, Nov., pp. 473s–8s.

The excellent resistance of 'Inconel' to stress-corrosion cracking has stimulated considerable interest in the advantages it offers in the field of nuclear power (e.g., as a material of construction for heat exchangers, primary-cooling-system piping, reactor-coolant pumps and valves, and for cladding the interior of the reactor vessel). It is essential in nuclear-power reactor systems that weldments be free from defects, and the necessity of welding unusually heavy sections, sometimes several inches

Material	Ni %	Cr %	Fe %	Mn %	Nb + Ta %	C %	Ti %	Si %	S %	Cu %	Co %
MIL-4N85 ..	67·0	14·7	7·5	7·7	2·0	0·04	0·40	0·50	0·007	0·03	0·07
MIL-EN87/RN87	72·0	20·0	1·0	3·0	2·6	0·03	0·30	0·30	0·009	0·02	0·04

thick, has aggravated the welding problems involved. A number of welding electrodes and filler wires conforming to A.W.S./A.S.T.M. codes have been ruled unsatisfactory for some nuclear-power applications because even the few weld defects permitted by the codes cannot be tolerated in critical areas. Earlier work, in particular that reported by FRAGETTA and PEASE*, had indicated that some of the requirements could be met with existing materials, but certain objectionable characteristics limited their field of application, and the MIL Type 4N85 covered electrode and the EN87/RN87 inert-gas filler wire which formed the subjects of the investigation now reported were therefore developed, through months of concentrated research, to fill the need for more versatile welding materials. The extensive tests and evaluations described have shown both to be well suited for welding 'Inconel' in fabrication of nuclear-power plant.

The 4N85 electrode deposits weld metal of the composition given in the table above. It is intended for use in welding 'Inconel', producing dissimilar welds with materials such as carbon steel and stainless steels, and for overlaying carbon steel. The EN87/RN87 inert-gas-shielded filler wire complements the covered electrode; it deposits non-age-hardenable welds and overlays (*see* composition in table above), and is suitable for producing welds between 'Inconel' and carbon steel or stainless steel.

The degree to which the electrode and filler wire satisfy requirements was assessed on the basis of data gained from side-bend and tensile tests and X-ray examination. The following were evaluated:

(1) Highly-restrained butt welds in 'Inconel'/'Inconel' and 'Inconel'/carbon-steel combinations.

(2) Highly-restrained overlays on carbon steel.

(3) In the case of the electrode, fixed-position butt welds in 'Inconel' pipe (1-in. wall, 11-in. outer-diameter).

(4) All-weld-metal specimens (in the case of the electrode, this phase involved determination of stress-rupture properties and room- and high-temperature tensile strength, and study of the effect of stress-relieving heat-treatments; the filler wire specimens were subjected to tensile tests at room temperature).

(5) In the case of the filler wire, welds simulating those used in joining 'Inconel' tube to overlayed tube sheet.

A study was also made of the compatibility of MIL-EN87 deposits with weld metal deposited by other types of nickel-chromium-iron filler wire and covered electrode.

The author's summary of the conclusions drawn from the data presented is quoted below:

'(1) The MIL-4N85-type covered welding electrode has produced crack-free and porosity-free welds, in all positions and under high restraint, in the 15 per cent. chromium, 7 per cent. iron, nickel-base alloy, and between nickel-chromium-iron alloy and carbon steel.

'(2) Overlays on carbon steel, and dissimilar joints between nickel-chromium-iron alloy and carbon steel, made using the MIL-4N85 type covered electrode, have been subjected to the normal stress-relieving temperatures used for steels without any adverse effect on the weld-metal properties.

'(3) The MIL-4N85-type covered electrode has deposited weld metal having good physical properties, with joint efficiencies of over 90 per cent., in short-time tensile tests from room temperature through 2000°F. (1095°C.), and stress-rupture joint efficiency of 100 per cent. through 1350°F. (735°C.).

'(4) The MIL-EN87/RN87-type filler wire for inert-gas-shielded welding has produced crack-free and porosity-free welds, under conditions of high restraint, in the 15 per cent. chromium, 7 per cent. iron, nickel-base alloy, and between nickel-chromium-iron alloy and carbon steel, and is well suited for overlaying carbon steel in heavy sections.

'(5) Carbon-steel overlays, and dissimilar joints between nickel-chromium-iron alloy and carbon steel, made using MIL-EN87-type filler wire, have also been subjected to the normal stress-relieving temperatures used for steels without any adverse effect on the weld-metal properties.

'(6) Tube to tube-sheet welds, free from cracking and porosity, have been made successfully between EN87 overlays and nickel-chromium-iron-alloy tubes with the gas tungsten-arc process without the addition of filler metal.

'(7) The MIL-4N85 and MIL-EN87 types of welding material have been welded into deposits of other types of nickel-chromium-iron covered

* *Ibid.*, 1959, vol. 38, Apr., pp. 347-56: see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 6, p. 204.

electrodes and filler wires, such as the 3N12 electrode and EN62 filler wire, without adverse effect on weld quality.'

Readers' attention is directed to an independent investigation of the covered electrode reported by G. F. McKITTRICK and W. A. OWCZARSKI and referred to in *Nickel Bulletin*, 1960, vol. 33, No. 12, p. 321.

Welding of 'Inconel X' in the Fabrication of Pressure Vessels

H. P. SCHANE and E. E. WEISMANTEL: 'Fabrication Principles for Welded 'Inconel X' Structures.'
Welding Jnl., 1960, vol. 39, Nov., pp. 479s-83s.

In recent years there has been an increased need for pressure vessels which will operate reliably under relatively high stress levels at temperatures above 1000°F. (540°C.), particularly in applications requiring weight to be held to a minimum. Four years ago, the Budd Company received a design contract to develop a large welded pressure vessel to requirements placing considerable restrictions on weight. This paper describes the fabrication conditions and the other factors entailed in the development both of the first unit and of a subsequent unit which was to be exposed to even severer service conditions. 'Inconel X' was selected as the material of construction, on account of its proved reliability in applications involving high stress at temperatures in the range 1000°-1300°F. (540°-705°C.), and because of the practicability of fabricating heat-treated welded structures. The designing of structures in nickel-base age-hardenable alloys is critical in the low ductility range 1150°-1350°F. (620°-735°C.) which corresponds to the ageing range. Moreover, practically all the butt welds were not only to be made from one side of the vessel, but were also required to satisfy the following standards: 100 per cent. penetration, with uniform reinforcement at both root and face; no sharp contours were to be present at face or root; heat input was to be kept to a minimum so as to minimize shrinkage and distortion; no cracking or elongated voids were to be acceptable; to minimize shrinkage all weld edges were, where possible, to be butted together with no gap.

In this paper, the authors allude to the manufacturing techniques which affect the design and serviceability of critical units, and discuss, in detail, various joint designs and the effect of these designs on weld-joint efficiency. The importance of weld-cleaning is emphasized, and an outline is given of welder-qualifying procedures employed to assess ability to produce consistent high-quality welds for service at elevated temperatures. The requirements of post-welding stress relief and final heat-treatment are considered.

Use of Steel Castings in Aeronautical Applications

See abstract on p. 38.

Uses and Advantages of Stainless-Steel/Copper Bimetallic Heat-Exchanger Tubing

W. G. ASHBAUGH and S. E. DOUGHTY: 'Bimetallic Heat-Exchanger Tubes Solve Dual Corrosion Problem.'
Metal Progress, 1960, vol. 78, Dec., pp. 115-17, 128, 130, 132.

In the operation of chemical-processing plants located in coastal areas, engineers are frequently confronted with the problem of providing heat-exchanger tubing capable of withstanding corrosion both by the salt-water or brackish river water commonly used as a coolant and by the process liquid or gas (which will generally be totally different in corrosive characteristics). Stainless-steel heat-exchanger tubing, which is normally resistant to corrosive attack on the process side, is susceptible, during long exposure to the chloride ions present in brackish water, to pitting and stress-corrosion cracking. An answer to this problem has been sought in the use of bimetallic tubing (i.e., tubing comprising stainless steel on the process side and a copper-base alloy on the cooling-water side). Union Carbide Chemicals Company has employed this type of composite tubing, produced by drawing copper or brass over chromium-nickel stainless-steel welded tubing, on three occasions as a means of solving the problem of dual corrosion.

In this article the authors outline the operating conditions and corrosion problems which led to the use of bimetallic tubing in each of these three cases, and refer to the advantages which have been derived from its use. In one application (a vertical condenser handling hot corrosive gases on the tube side and brackish river water on the shell side), the bimetallic tubing has given 5 years' uninterrupted service, and is expected to last 10 years, whereas the most effective stainless-steel tubing previously used had lasted only 22 months.

Low-Temperature Properties of Nickel-containing Alloys and Steels

R. E. LISMER: 'The Properties of Some Metals and Alloys at Low Temperatures.'
Jnl. Inst. Metals, 1961, vol. 89, Jan., pp. 145-61.

To satisfy the increased demand for data on the properties of materials potentially suitable for use in plant designed for low-temperature service (particularly in the transportation and storage of liquid gases), a programme of laboratory tests covering temperatures down to −196°C. was carried out on a range of alloys and steels. The present paper records the data derived from investigation of the properties of four classes of wrought material [in the form of plate ½–¾ in. (1·25—1·9 cm.) thick]:

(1) *Copper and copper alloys*: arsenical copper; brass; 90-10, 80-20, and 70-30 cupro-nickels; 'Kunifer 5' and 'Kunifer 20'; 'Superston 40' manganese-aluminium bronze.

(2) *Nickel alloys*: 'Monel'; 'Inconel'.

(3) *Austenitic stainless steel*: titanium-stabilized 18–8 chromium–nickel steel with and without 3 per cent. molybdenum.

(4) *Low-carbon nickel steels:* 2¼, 3½ and 9 per cent. nickel grades.

The materials studied were subjected to plain and notched tensile tests, U.S. Navy tear tests, and Charpy V-notch impact tests.

The results of these tests, presented in tabular and graphical form, show that copper, cupro-nickel and the 'Kunifer' alloys slightly increased in strength with decrease in testing temperature, and retained excellent ductility down to −196°C. The ductility of brass, though appreciably lower, was unaffected by fall in temperature. The ductility of the manganese-aluminium bronze (tested in the notched condition) was low, and impact energy decreased appreciably as the test temperature was lowered to −196°C.

Specimens of 'Monel' and 'Inconel' were subjected only to Navy tear tests. The maximum load was found to increase considerably with fall in temperature from ambient to −196°C. Both materials showed excellent ductility and tough fracture characteristics over the temperature range studied.

The austenitic stainless steels exhibited excellent low-temperature properties in both tensile and standard tear tests, but were found to be sensitive to notches severer than those specified for the standard tests (a sensitivity which was reflected in strength values rather than in ductility).

The data obtained in tests on the three grades of low–carbon nickel steel demonstrated the suitability of these materials, when correctly heat-treated, for use at temperatures down to those recommended in *A.S.T.M. Specification A*300: i.e., down to −75°F. (−60°C.) in the case of the 2¼ per cent. nickel steel; down to −150°F. (−100°C.) in the case of the 3½ per cent. nickel steel; and down to −320°F. (−196°C.) in the case of the 9 per cent. nickel steel.

Storage and Transportation of Liquid Fluorine

J. M. SIEGMUND: 'Transportation-Transfer-Storage of Liquid Fluorine.'

Proc. Propellant Thermodynamics and Handling Conference, Engineering Experiment Station, Ohio State University, Special Report 12, June 1960, pp. 151–60.

Early in the development of rocket engines, it became evident that elemental fluorine could be used to full advantage as an oxidizer only if some practical means were devised for storing and shipping it in liquid form. In November 1953, the General Chemical Division of Allied Chemical Corporation initiated work (sponsored by Wright Air Development Center) to develop and test a system for the bulk storage and transport of liquid fluorine.

Two storage tanks were initially constructed, the outer and intermediate chambers of which were fabricated from Type 304 18–8 stainless steel, and the product tank and product piping from 'Monel'. Subsequently, however, carbon steel was used for the outer shell. Of the materials of construction which might have been used for the product chamber, product piping and other parts wetted by fluorine (nickel, 'Monel', stainless steel, aluminium), 'Monel', which combines satisfactory strength with excellent cryogenic properties and high resistance to firing with fluorine, was selected as the most suitable. It is stated that a typical fluorine valve on a transport or storage tank would incorporate a 'Monel' or stainless-steel body, stem and plug, a copper seat, and a primary seal comprising a 'Monel' bellows backed up by a packing gland fitted with 'Teflon' chevron rings. The fluorine pressure gauges used for transport and storage tanks are of the compound bourdon type. All parts wetted by fluorine are in 'Monel'.

In the present paper the authors discuss the design and testing of the initial pilot tanks, and then refer to the tanks and procedures subsequently developed for bulk shipment of liquid fluorine.

Materials for Handling Fluorine

E. L. WHITE and F. W. FINK: Materials of Construction for Handling Fluorine.'

Proc. Propellant Thermodynamics and Handling Conference, Engineering Experiment Station, Ohio State University, Special Report 12, June 1960, pp. 161–81.

The advantages offered by fluorine as an oxidizer for rocket engines are, to a certain extent, offset by the handling and storage problems associated with the element's toxicity, low boiling point and high reactivity. In the present paper the authors collate the considerable amount of information available on the resistance of materials to corrosion by fluorine (the review is based on a *bibliography* of 52 items), and evaluate the suitability of metallic and non-metallic materials for use as materials of construction in contact with fluorine.

The paper is in three sections. In the introduction, consideration is given to the corrosion problems involved in handling fluorine (fluorine is the most electronegative of all the elements). In the two main sections, the authors are concerned with resistance to corrosion by fluorine in, respectively, the gaseous and liquid state. The corrosion data tabulated relate to magnesium and magnesium alloys, nickel and nickel alloys, titanium and titanium alloys, iron, zirconium, tantalum, chromium and nickel electrodeposits, silver solder, copper, thorium, vanadium, uranium, rhenium, platinum, silicon, tin, stainless steels, and various organic and inorganic non-metallic materials.

The authors' survey leads them to the conclusion that, though no material is completely inert to this extremely active element, many of the common materials of construction can, when employed in the established temperature ranges, be expected to give acceptable service. Nickel alloys are suitable for use up to 1200°F. (650°C.); aluminium and magnesium up to 900°F. (480°C.); copper, and possibly thorium, up to 700°F. (370°C.); pure iron up to 600°F. (315°C.); low-silicon mild steels up to 400°F. (205°C.); and titanium and zirconium up to 300°F. (150°C.). Chromium electrodeposited coatings are

satisfactory up to at least 400°F., and nickel coatings at even higher temperatures. The performance of tantalum, tin, silver, lead and platinum is adequate at room temperatures, but silicon, vanadium, rhenium and uranium are attacked even at temperatures below room temperature.

Fluorine in the liquid state (at liquid-nitrogen emperatures) is more corrosive than in the gaseous state at room temperature. The following materials are considered suitable for use with liquid fluorine: nickel and nickel alloys; stainless steels; aluminium; magnesium; mild steel; titanium; tantalum; zirconium.

Except in isolated applications, the only organic materials which can be used with either liquid or gaseous fluorine are the fluorocarbons (polytetrafluoroethylene is deemed the most satisfactory). Of the inorganic materials, alumina is regarded as very resistant to attack. Glass, asbestos and some cermets may find limited application, but carbon materials are not recommended for use at elevated temperatures.

Direct Nickel Plating of Hardenable Stainless Steel

See abstract on p. 31.

Electrodeposition of Iron-Chromium-Nickel Alloys: Influence of Brightening Agents

See abstract on p. 32.

Relationship between Electron Configuration and Passivity in Chromium-Nickel-Iron Alloys

H. G. FELLER and H. H. UHLIG: 'Relation of Electron Configuration to Passivity in Cr-Ni-Fe Alloys.'

Jnl. Electrochemical Soc., 1960, vol. 107, Nov., pp. 864–8.

In the chromium-nickel stainless steels, optimum passivity is associated with a chromium content of at least 12 per cent. This critical concentration has been related to the tendency of an 'unfilled' *d* band (or uncoupled *d* orbitals) of chromium to fill (or become coupled) with electrons donated by iron, a process which is assumed to be just complete at 12 per cent. Larger amounts of alloyed chromium correspond to residual uncoupled electrons or vacancies in surface atoms of chromium, accounting for an alloy best able to chemisorb its environment (e.g., O_2+H_2O) and become passive in a manner similar to pure chromium. Below 12 per cent. the *d* orbitals of chromium are coupled, and the alloy has chemical properties more nearly resembling iron (i.e., it is not passive). In the present paper the authors record and discuss the results of an investigation initiated to explore further electron interaction in relation to passivity.

The passive behaviour of the alloys selected for study (vacuum-melted single-phase chromium-nickel-iron alloys containing 20, 40, 50 or 60 per cent. nickel) was evaluated, as a function of chromium content, by determination of critical anodic current densities to produce passivity in 1·28 *N* sulphuric acid at 25°C.

In the case of the 20 and 40 per cent. nickel series of alloys, major discontinuities in the slope of the curves were found to approximate to the chromium/iron ratio 12/88; in the 50 and 60 per cent. nickel series, the discontinuities approximated to the chromium/nickel ratio 14/86. These ratios correspond to observed critical compositions for passivity in the chromium-iron and chromium-nickel binary systems. In the case of the 50 and 60 per cent. nickel alloys, further discontinuities occurred at the critical binary chromium/iron ratio, a behaviour which is interpreted in terms of separate electron interaction between chromium and iron in the ternary system, distinct from that between chromium and nickel.

Flade or activation potentials became more active with rise in chromium content, corresponding to a more stable passivity. In accord with greater stability, the average time for breakdown of passivity increased exponentially with chromium content.

Passivity in 18-8 and 18-8-Mo Steels

P. BERGE: 'Study of the Degree of Passivity in 18-8 Stainless Steels, with Particular Reference to the Electrochemical Behaviour of 18-8-Molybdenum Steel.'

Mémoires Scientifiques de la Revue de Métallurgie, 1960, vol. 57, Sept., pp. 699–704.

The investigations reported were undertaken in an attempt to throw light on the factors involved in the passivation and depassivation of austenitic stainless steels, in particular those of 18-8-Mo type.

Polarization curves were determined in 18*N* sulphuric acid, and the electrochemical-reduction technique was employed in measuring the degree of passivity exhibited by 18-8 steels. To explore the validity of the hypothesis explaining passivity in terms of oxygen adsorption at the surface of the steel, polarization curves were obtained in 20 per cent. sulphuric acid containing dissolved oxygen.

It is concluded that a 2 per cent. addition of molybdenum considerably influences the surface stability of 18-8 steels in sulphuric acid; that oxygen dissolved in the electrolyte is reduced (in the absence of an external current) in preference to the protective surface film; and that the composition of the protective film is not constant.

Influence of Hydrogen on the Tensile Properties of Stainless Steel

R. BLANCHARD, J. PELLISIER and M. PLUCHERY: 'Influence of Hydrogen on the Tensile Rupture Characteristics of Stainless Steels.'

Jnl. Nuclear Materials, 1960, vol. 2, Sept., pp. 216–24.

Although the use of hydrogen as a coolant in nuclear reactors offers considerable advantages, it also poses certain problems, of which compatibility with the materials of construction is one of the most important. The investigation described was undertaken to establish the degree to which stainless steel (a material under consideration for use in canning) would be embrittled as a result of absorption of hydrogen.

Wire specimens of the steel studied (nominal composition: carbon 0·12, manganese 1·23, silicon 1·1, copper 0·08, chromium 18, nickel 10, per cent.) were cathodically charged with hydrogen, and then subjected to tensile tests and electron-microscopical examination.

From the results presented the authors conclude that hydrogen charging markedly affects tensile characteristics. At a hydrogen content in the region of 50 cc. NTP/100 g., ultimate tensile strength was only 80 per cent. of the initial value, and the value for reduction-in-area was only 55 per cent. (*vis-à-vis* 80 per cent. for the uncharged material).

Details are given of a special two-stage replica technique which enabled the fracture surfaces of the small (0·3-mm.-diameter) tensile specimens to be examined by electron microscopy. Although the specimens showed no sign of embrittlement over the range of hydrogen contents investigated, the appearance of the fracture surface was observed to change gradually with increase in hydrogen content.

Corrosion Inhibitors for Fuming Nitric Acid

S. A. LONG, W. H. BERGDORF and E. J. KINSLEY: 'The Development of Corrosion Inhibitor for Fuming Nitric Acids.'

Proc. Propellant Thermodynamics and Handling Conference, Engineering Experiment Station, Ohio State University, Special Report 12, June 1960, pp. 539–51.

The work reported was initiated to develop inhibitors for fuming nitric acid which would prove more effective in minimizing corrosion and formation of scale and sludge than hydrofluoric acid. The efficacy of the additions studied was evaluated in relation to their influence on the corrosion behaviour of welded and unwelded specimens of three materials representative of those used for storage containers and missile components: A.I.S.I. Type 304L (low-carbon 18-8) stainless steel, '17-7 P.H.' steel, and 6061-T6 aluminium alloy.

On the basis of the results of previous investigations, the inhibitors listed in the table below were selected for study. Depletion rates and optimum inhibitor concentrations were determined in Types I and III fuming nitric acid, and, to supplement the data on corrosion behaviour and sludge formation, welded specimens were subjected to mechanical testing after 30 days' exposure [at 120°F. (50°C.)] to the liquid and vapour phases of the various inhibited-acid systems. In the final phase of the programme, acid inhibited with additions (1), (7) and (8) was stored for 58 days, at 70°, 120° and 160°F. (20°, 50° and 70°C.), in containers fabricated from the three test materials.

	Inhibitor	Optimum Concentration wt. %
1	HF	0·70% as HF
2	1 mole KF+2·3 mole HF	0·75% as HF
3	$NH_4F.HF$	0·50% as HF
4	$LiIO_3$+HF	0·30% $LiIO_3$+0·60%HF
5	KIO_4+HF	0·50% KIO_4+0·60% HF
6	Na_3PO_4+HF	0·40% as H_3PO_4+0·60%HF
7	H_3PO_4+HF	0·40% as H_3PO_4+0·60% HF
8	$NH_4PF_6.NH_4F$	0·30% as HF

The optimum concentrations established for the individual inhibitors are reproduced in the table. The data presented show that ammonium hexafluorophosphate was more effective in inhibiting corrosion than hydrofluoric acid. Exposure to the inhibited-acid systems had no significant effect on the mechanical properties of the welded specimens.

Corrosion in a Stainless-Steel Gas Scrubber

J. T. FIRESTONE: 'Rapid Pitting Corrosion on Gas Scrubber.'

Corrosion, 1960, vol. 16, Dec., pp. 9–10.

The investigation described originated in the occurrence of severe pitting in a Type 316 (18-12-Mo) stainless-steel gas scrubber only three weeks after its installation in a pulp mill. The scrubber, of venturi throat type, incorporates four banks of nozzles and throats, by means of which sodium salts are removed from the flue gas from the sulphate-pulp recovery furnace. At the scrubber entrance, the gas is sprayed with water and, its temperature falling rapidly from about 300°F. (150°C.) to about 150°F. (65°C.), the salt tends to adhere to the wall in stagnant areas. The rapid pitting occurred only in those areas where the fly ash had not been washed away.

In subsequent plant corrosion tests, the corrosion-resistance of specimens of titanium, 'Hastelloy C', 'Monel', 'Inconel', nickel, Type 317 stainless steel, 'Everdur' and 'Ni-O-Nel' was found to be no better under the specific service conditions than that of Type 316 steel, and the results of an investigation of the feasibility of using non-metallic protective coatings of stainless steel were no more satisfactory. The test programme did, however, draw attention to five points of significance for the design of future scrubbers: (1) crevices and square corners should be eliminated; (2) to avoid formation of crevices, lap welds should be produced from the inside; (3) the internal bracing of the scrubber should be round and not flat; (4) sufficient showers should be installed to wet the walls in all areas of stagnant gas flow; (5) the initial water spraying should take place at the smallest opening into the scrubber.

Performance of an 18-12-Mo Steel Valve in Hot Sulphur Dioxide

'Stainless-Steel Valve Survives 31-Year Sulfur-Dioxide Exposure.'

Corrosion, 1960, vol. 16, Dec., p. 24.

In 1929 an 8-in. (20-cm.) Y-valve fabricated from A.I.S.I. Type 316 18-12-Mo stainless steel was installed in the sulphite-pulp cooking system of

the Maine Mill of the Eastern Fine Paper and Pulp Division of Standard Packing Corporation. Located in the relief line between the digesters and the hot-acid accumulator, the valve has since been in continuous operation under conditions involving exposure to hot sulphur-dioxide gas at a temperature of 270°F. (130°C.) and pressures in the range 45–50 p.s.i.g. This note draws attention to the excellent performance of the valve over the 31-year period of service, and the need for basing selection of a material of construction on careful study of the specific corrosion conditions involved.

Use of 'CD-4MCu' Stainless Steel for Torpedo-Tube Breech Doors

E. A. SCHOEFER: 'Navy Picks Cast Stainless Alloy.'
Metal Progress, 1960, vol. 78, Nov., p. 122.

The precipitation-hardenable cast steel 'CD-4MCu' was developed, under the aegis of the Alloy Casting Institute, to provide a material combining high strength with high corrosion-resistance. The steel, which contains chromium 25–27, nickel 4·75–6, molybdenum 1·75–2·25, copper 2·75–3·25, per cent., exhibits excellent resistance to stress corrosion and has, on this account, been used by the U.S. Navy as a material for the breech doors of torpedo-tube assemblies. This short article outlines the properties which render the steel suitable for this application.

Use of 'K Monel' for the Arresting Hooks of Carrier-based Aircraft

A. R. MEAD: ''K Monel' Solves Arresting-Hook Problem.'
Metal Progress, 1960, vol. 78, Sept., pp. 117–20.

Of the many design problems peculiar to naval aircraft, one of the most critical is that associated with the arresting hook which snags a wire stretched across the flight deck of an aircraft carrier and brings the aeroplane to a stop. Some of the landing shock is taken up as the wire is played out, but most of it is absorbed through the arresting hook. Loads on the tail section are tremendous, since fleet aircraft weigh more than 10 tons and land at over 100 m.p.h. In designing an arresting hook for the S2F-1 Tracker, a U.S. Navy anti-submarine aeroplane, the engineers of Grumman Aircraft Engineering Corporation were confronted with the problem of finding a material of construction which would not only satisfy strength requirements, but also be non-magnetic (to prevent interference with the electronic submarine-locating device carried in the tail of the aeroplane).

'K Monel' (a nickel-base age-hardenable alloy containing copper 30, aluminium 3, per cent.) was finally selected for use on account of its good flash-welding characteristics, excellent corrosion-resistance, good reproducibility of properties in the form of forgings, and its non-magnetic nature. In this article the author discusses the factors involved in the design, fabrication and heat-treatment of the alloy for this purpose, and notes the significant improvement which its use has achieved in the service life of the arresting hooks.

Cladding with the Gas-Shielded Process

R. D. ENGEL: 'New Techniques for Cladding with the Gas-Shielded Process.'
Welding Jnl., 1960, vol. 39, Dec., pp. 1222–9.

In an attempt to modify the characteristic penetration pattern (and minimize the excessive dilution) associated with the use of the stringer-bead technique in fusion cladding by the gas-shielded process, the author investigated the feasibility of adapting for the purpose an oscillating technique employing a cold-filler-wire addition. This technique involved oscillating the welding barrel as a sinusoidal pendulum, with a cold-wire positioner rigidly attached to the oscillating barrel, a procedure which produced a wider bead with less average dilution than that obtained with the stringer-bead technique. The objections to the sinusoidal-pendulum method were four-fold: (1) the difficulty of adding a cold filler wire under an oscillating arc; (2) the continually changing arc length; (3) the limited usable range of oscillation width; and (4) the localized areas of high dilution at the bead edges which can cause metallurgical difficulties.

The work to overcome these problems (carried out mainly with stainless-steel electrodes), and the cladding procedure finally developed, are reported in this paper. Suitable overlay applications are discussed.

It was found that high-deposition rates are obtainable with the gas-shielded welding process, using d-c reverse polarity current and electrode extensions of up to 3 in. (7·5 cm.). The long electrode extensions result in deposition rates 50–100 per cent. higher than those obtainable with normal extensions of $\frac{1}{2}$–$\frac{3}{4}$ in. (1·25 – 1·9 cm.) and substantially reduce weld-metal dilution.

Combining the extended-electrode gas-shielded process with the convelinear oscillating device provided an improved fusion-cladding process capable of producing high-quality overlays at high rates of deposition. The process is applicable to deposition of, *inter alia*, stainless steel and nickel- and copper-base alloys.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Trade Marks*.

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